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CONTENTS

General Design and Research

Reducing Horsepower and Noise of Automotive Cooling-Fans—A. D. Gardner 109

Streamlining Applied to Automobiles—Othmar K. Marti 126

Influence of Carbureter Setting and Spark Timing on Knock Ratings—John M. Campbell, Wheeler G. Lovell and T. A. Boyd 129

Effect of Sound Intensity on Knock Ratings—Harry F. Huf, J. R. Sabina and J. Bennett Hill 134

Bouncing-Pin versus Throttle-Audibility—Neil MacCoull 137

Time Lage in Detonation Determinations—Neil MacCoull 139

Low-Temperature-Starting Development of Automobile Engines—P. J. Kent 141

Automotive Research—Tentative Recommended Practice for Conducting Antiknock Tests 164

Notes and Reviews 174

Production Engineering

Corrosion Prevention—Lessiter C. Milburn 148

The Place of Industrial Trucks in Automotive Materials Handling—C. B. Crockett 158

Gluing in Aircraft Construction—T. R. Truax 167

Transportation Engineering

Effective Traffic Control 166

Aeronautic Engineering

Airplane Fuel-Line Temperature—O. C. Bridgeman, C. A. Ross and H. S. White 121

News of the Society

Aeronautic Meeting in September 105

National Production Meeting 105

Transportation Meeting Plans 106

Section Officers for 1931-1932 107

Chronicle and Comment 108

Obituaries 170

Personal Notes of the Members 171

Applicants Qualified 172

Applicants for Membership 173

News of Section Meetings 173

The purpose of meetings of the Society is largely to provide a forum for the presentation of straightforward and frank discussion. Discussion of this kind is encouraged. However, owing to the nature of the Society as an organization, it cannot be responsible for statements or opinions advanced in papers or in discussions at its meetings. The Constitution of the Society has long contained a provision to this effect.

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S·A·E JOURNAL

VOL. XXIX, No. 2
AUGUST, 1931

Aeronautic Meeting in September

THE NATIONAL AIR RACES have returned to the scene of the 1929 event, and if Cleveland's handling of the occasion in that year is duplicated this year, the races should be a pronounced success.

The 20th National Aeronautic Meeting of the Society will be held Sept. 1, 2 and 3, in the Hotel Statler, with technical sessions in the mornings and evenings, leaving the afternoons free from conflict with the race events. As shown by the program on the following page, many of the latest developments in aeronautic engineering are to be treated by various engineers whose names have become familiar during the last few years in the industry. The recent development in Autogiro theory and design, the development and uses of controllable-pitch and automatic propellers and the use of magnesium in aircraft engines are to be discussed.

Important Engine Papers

One of the outstanding papers will be that on the study of aircraft vibration, by S. J. Zand, of the Pioneer Instrument Co. The data presented therein are the results of months of research, and, although a great portion is devoted to vibration with particular relation to the instruments and the instrument panel, an entire method of study of all aircraft vibration is presented.

Other engine papers will be on the subject of turbo superchargers; future developments in liquid cooling, with particular reference to sealed liquid-cooling possibilities; and fuel injection with spark ignition. This last paper is a continuance of a subject presented before the Society at a previous meeting, the research on which has been carried to a further point.

Aircraft Development and Maintenance

Aerodynamics will receive consideration in a paper on the determination of flight load-factors wherein will be presented data resulting from research carried on at the Massachusetts Institute of Technology.

Thursday night, Sept. 3, is to be devoted to a dinner. The old statement that the man with the longest arm gets the most to eat will hold in this case, as the usual formal dinner or banquet, as some people have insisted on calling it, will be replaced by a Dutch Supper. No dinner clothes are to be worn, and the plans promise plenty to eat, a good time and a profitable evening.

The Air Races this year are again under the official management of Clifford W. Henderson, which in itself should go far toward assuring their success.

Members planning to attend the meeting and the races should bear in mind that the Hotel Statler will be the headquarters of the Society and make their reservations sufficiently in advance to assure them good accommodations in what will be a crowded city.

National Production Meeting

DETROIT was selected as the place for the 1931 National Production Meeting of the Society to be held at the Book-Cadillac Hotel, Oct. 7 and 8, because that city is the largest individual manufacturing center in the automotive industry and is centrally located with respect to other centers such as Buffalo, Cleveland, Toledo, Chicago and Milwaukee. In preparing the program for the meeting, the Production Activity Committee has made a special effort to schedule problems for discussion that will make it profitable for production engineers and executives from other cities to attend the meeting with a minimum amount of time away from their plants and to give them an opportunity to hear and discuss some of the principal manufacturing problems of the day.

Five papers dealing with production-management problems and new developments in production equipment will occupy three technical sessions. The subjects to be discussed are various methods of welding, the cleaning and preparation of metal surfaces for coated finishes, the hot-coining of drop forgings for greater accuracy and economy, permanent-mold casting practice and inventory control in the plant.

Arrangements are being made for only one plant visit, which will be to a plant selected for its interest to production engineers, so as to get the most out of this feature of the meeting.

The Production Dinner arrangements will be simple but the dinner-session will be exceedingly interesting and instructive. A capital speaker is to be invited to address the gathering and

arrangements are under way for a demonstration lecture on Electrons at Work and at Play, through the courtesy of the Westinghouse Electric & Mfg. Co.

As previously, the Detroit Section of the Society is giving its very helpful cooperation to the Production Activity Committee in arranging for the meeting, further details of which will be published in the September issue of the S.A.E. JOURNAL.

Transportation Meeting Plans

THE Ninth Annual National Transportation Meeting of the Society will be held this year in the city of Washington at the Shoreham Hotel. The dates originally set have been changed to Oct. 27, 28 and 29. There are to be six technical sessions, two inspection trips, and probably a call on President Hoover at the White House.

Problems of prime importance in the field of both freight and passenger motor-vehicle transportation will be treated in papers dealing with the relation of the motor transportation engineer to motor-transport operations; the railroads and motor transportation; application of Diesel engines in commercial motor-vehicles; and lubrication of both the engine and the chassis. There are also to be a discussion of what the Bureau of Standards is doing for business, a discussion of motorcoach chassis and bodies, including all-metal bodies, and a report in the nature of a paper that will be based on a broad survey now in progress of the equipment and operation of fleet owners' repair shops and the service and maintenance furnished by manufacturers' and commercial repair shops. The authors for all of the papers have been selected and are men of national reputation, well qualified to discuss their respective subjects.

Through the courtesy of the Washington Railway & Electric Co., arrangements are being made for a visit to the properties of the company and possibly a sightseeing trip to the principal points of interest in the capital city. Another trip will be a visit to the Bureau of Standards, with inspection particularly of those sections whose work is of special interest to transportation engineers.

The National Transportation Dinner will be especially attractive this year, as arrangements are being made, with the helpful cooperation of the Washington and Baltimore Sections of the Society, to secure speakers of national reputation.

CALENDAR

National Meetings

20th National Aeronautic Meeting—Sept. 1 to 3

Hotel Statler, Cleveland

In conjunction with the National Air Races

Production Meeting—Oct. 7 and 8

Book-Cadillac Hotel, Detroit

Transportation Meeting—Oct. 27 to 29

Shoreham Hotel, City of Washington

20th National Aeronautic Meeting Program

Hotel Statler, Cleveland — Sept. 1, 2 and 3

Tuesday, Sept. 1

10:00 A.M.—ENGINES

Sealed Liquid-Cooling—J. H. Geisse, Comet Engine Co.

The Turbo Supercharger—O. Chenoweth and A. L. Berger, United States Air Corps, Wright Field.

8:30 P.M.—AIRCRAFT

A Study of Airplane Vibration, with Particular Reference to Vibration at the Instrument Board—S. J. Zand, Pioneer Instrument Co.

A Rational Method of Determining Flight Load-Factors—J. S. Newell, Massachusetts Institute of Technology

Wednesday, Sept. 2

10:00 A.M.—AIRCRAFT

Progress of Autogiro Development—A. E. Larsen, Autogiro Co. of America

Magnesium in Aircraft Construction—G. D. Welty, Aluminum Co. of America

8:30 P.M.—ENGINES

Further Investigation of Fuel Injection with Spark Ignition in an Otto-Cycle Engine—E. S. Taylor and George L. Williams, Massachusetts Institute of Technology

The Development of an Apparatus for the Study of Combustion in High-Speed Diesel Engines—A. M. Rothrock, National Advisory Committee for Aeronautics

Thursday, Sept. 3

10:00 A.M.—PROPELLERS

Controllable and Automatic Aircraft Propellers—D. A. Dickey and Lieut. O. R. Cook, United States Air Corps, Wright Field

Aeronautic Propellers—F. W. Caldwell, Hamilton Standard Propeller Co.

8:30 P.M.—DUTCH SUPPER

Section Officers for 1931-1932

FOLLOWING is the list of officers elected at the close of last season by the 20 recognized and 2 probationary Sections of the Society to serve until the end of the Section administrative year on May 31, 1932. The new officers and their committees have been active since their election and appointment in making plans for the administration of the affairs of their respective Sections and for meetings to be held during the autumn, winter and spring.

Section activity has been accelerating at an increasing rate during recent years, seven new recognized Sections and two probationary Sections having been organized since 1928, and the total Section membership having increased from 3616 in October, 1928, to 4643 in July, 1931. Attendance at monthly meetings of the Sections has also been greatly augmented, as the meetings have been made more interesting by means of better papers and speakers than in the past. The coming season is expected to show still further improvement in this respect, as each succeeding year's officers feel the responsibility to exceed, if possible, the best efforts of their predecessors.

The newer Sections have made highly commendable records in the way of attendance at meetings, excellence of programs and papers presented, and in membership growth. Similarly, several of the older Sections have in the last year or two exhibited greatly increased growth and enthusiasm.

Section Officers for 1931-1932

Baltimore Section

Chairman—A. Bruce Boehm, district manager, Standard Oil Co. of N. J., Baltimore.

Vice-Chairman—George E. Hull, vice-president, general manager, Parks & Hull, Inc., Baltimore.

Treasurer—Laurence F. Magness, president, Hercules Power Gasoline Co., Baltimore.

Secretary—Espy W. H. Williams, Automotive Trades Alliance, division of Automotive Service Bureau, Baltimore.

Buffalo Section

Chairman—Edward A. Oehler, general factory manager, Stewart Motor Corp., Buffalo.

Vice-Chairman—Alben F. Carlson, chief body draftsman, Pierce-Arrow Motor Car Co., Buffalo.

Vice-Chairman—William H. Schaefer, manufacturers sales department, Goodyear Tire & Rubber Co., Inc., Buffalo.

Vice-Chairman for Aeronautics—I. Machlin Laddon, aeronautic engineer, Consolidated Aircraft Corp., Buffalo.

Treasurer—Willard R. Vohrer, assistant chief engineer, Sterling Engine Co., Buffalo.

Secretary—Louis R. Jones, assistant chassis engineer, Pierce-Arrow Motor Car Co., Buffalo.

Canadian Section

Chairman—Frank B. Averill, factory manager, Durant Motors of Canada, Ltd., Toronto.

Vice-Chairman—George W. Garner, chief engineer, General Motors of Canada, Ltd., Oshawa, Canada.

Treasurer—W. E. Davis, assistant general manager, General Motors of Canada, Ltd., Oshawa, Canada.

Secretary—Warren Hastings, editor, manager, *Canadian Motorist*, Toronto.

Chicago Section

Chairman—Otto R. Schoenrock, director of engineering, Oliver Farm Equipment Co., Chicago.

Vice-Chairman—Leonard V. Newton, automotive engineer, Byllesby Engineering & Management Corp., Chicago.

Treasurer—C. J. Blakeslee, works manager, Walker Vehicle Co., Chicago.

Secretary—Harold Nutt, director of engineering, Borg & Beck Co., Beverly Hills, Ill.

Cleveland Section

Chairman—Carl F. Oestermeyer, sales engineer, Willard Storage Battery Co., Cleveland.

Vice-Chairman—Dale S. Cole, research engineer, Leece-Neville Co., Cleveland.

Treasurer—Walter S. Howard, chief inspector, salvage supervisor, White Motor Co., Cleveland.

Secretary—Hoy Stevens, superintendent of maintenance, Cleveland Railway Co., Cleveland.

Dayton Section

Chairman—Frederick William Sampson, assistant chief engineer, Inland Mfg. Co., Dayton.

Vice-Chairman—G. W. Frank, mechanical engineer, United States Army, Air Corps, Materiel Division, Wright Field, Dayton.

Treasurer—A. N. Wilcox, president, Dayton Wire Wheel Co., Dayton.

Secretary—Herbert C. Walters, chief engineer, Delco Aviation Corp., Dayton.

Detroit Section

Chairman—O. T. Kreusser, engineering tests, General Motors Proving Ground, Milford, Mich.

Vice-Chairman Representing Passenger-Cars—E. S. MacPherson, assistant chief engineer, Hupp Motor Car Corp., Detroit.

Vice-Chairman Representing Bodies—Roy F. Anderson, sales engineer, Murray Corp. of America, Detroit.

Vice-Chairman Representing Aeronautics—W. S. Pritchard, factory manager, Detroit Aircraft Corp., Detroit.

Vice-Chairman Representing Students—Alex Taub, development engineer, Chevrolet Motor Co., Detroit.

Treasurer—F. W. Marschner, western sales manager, New Departure Mfg. Co., Detroit.

Secretary—George B. Allen, chief engineer, Dodge Brothers Corp., Grosse Pointe Park, Mich.

Indiana Section

Chairman—H. M. Jacklin, associate professor of automotive engineering, Purdue University, West Lafayette, Ind.

Vice-Chairman—Louis Schwitzer, president, chief engineer, Schwitzer-Cummins Co., Indianapolis.

Treasurer—Charles Trask, engineer, Rockwood Mfg. Co., Indianapolis.

Secretary, Harlow Hyde, Indianapolis.

Kansas City (Probationary)

Chairman—Richard H. Van Ness, transportation manager, City Ice Co. of Kansas City, Kansas City, Mo.

Vice-Chairman—James A. Edwards, president, Jesco Lubricants Co., North Kansas City, Mo.

Treasurer—Orville Gilbert, owner, Gilbert Automotive Co., Kansas City, Mo.

Secretary—Clarence W. Whipple, chief mechanic, Allison Airplane Co., Independence, Mo.

Metropolitan Section

Chairman—Erwin H. Hamilton, assistant professor of automotive engineering, New York University, New York City.

Vice-Chairman—John F. Creamer, Wheels, Inc., New York City.

Vice-Chairman for Aeronautics—Charles Froesch, general service manager, Fokker Aircraft Corp., Teaneck, N. J.

Treasurer—M. C. Horine, sales promotion manager, International Motor Co., Grasmere, N. Y.

Secretary—A. L. Beall, engineer, Vacuum Oil Co., Ridgefield, N. J.

Milwaukee Section

Chairman—H. L. Debbink, superintendent of gasoline vehicles, Milwaukee Electric Railway & Light Co., Milwaukee.

(*Concluded on p.* 169)

Chronicle and Comment

Watch the Student! IN line with the recommendations of Ralph Teetor's Sections Committee, a number of our Governing Boards are including meetings of special interest to students in their 1931-1932 Section programs; further, they are hoping to bring many of the young engineers of our leading educational institutions more fully into contact with the broad picture of S.A.E. activity.

This will mean a great deal to the students, the Sections and the Society at large. The so-called hard-boiled practical engineer can show the student certain attributes that will combine well with books, laboratories and lectures to assure a happy industrial contact after commencement; whereas the student can bring to the seasoned technician a refreshing concept of plans, ideas and ideals that are still unspoiled by factory traditions and the gospel that "it can't be done."

Never believe that the engineering student of today is the unsophisticated and impractical individual so often pictured. By and large, he possesses the qualifications of a quick asset to almost any organization.

Post and Gatty Honored IT is too late to say anything new and it is difficult to voice adequate appreciation of the human and mechanical wonders of the Post-Gatty flight around the world. Praise and felicitations were heaped high for the benefit of the gallant flier and his navigator at the Aeronautical Chamber of Commerce banquet in New York City, where Post and Gatty were honored. Many S.A.E. members who accepted the Chamber's invitation to attend the affair were particularly impressed by Harold Gatty's brief reference to the simplified method of celestial navigation that he used so effectively on the flight. Through the application of this method, specifically adapted to aircraft work, the necessity for laborious computations is eliminated and valuable time is saved. Perhaps our Aeronautic Activities can arrange for a more complete technical presentation of this subject at one of our meetings.

Coming Aeronautic Events DETAILED reference to the program of the Society's 20th Aeronautic Meeting will be found in this issue of the S.A.E. JOURNAL and in the announcements that will soon appear. Meeting place, Cleveland. Date, Sept. 1, 2 and 3.

In cooperation with the Aeronautical Chamber of Commerce of America, the Society's Sections and National Activities will probably stage additional Aeronautic Meetings from time to time during the fall and spring months.

A very pleasant working relationship has for some time existed between the aeronautic engineering branches, as represented by the S.A.E., and the commercial branches, as represented by the A.C.C.A.

Summer Meeting Echoes LOW golf totals and high bridge scores, important as they may or may not have seemed at White Sulphur Springs, have yielded their places as topics of conversation to the features of the Summer Meeting that are destined to make automotive history. Traveling through the industry today, one hears a great deal of serious consideration being given to the design, research and operation features of the meeting. The whole story of streamline construction; mounting the engine in the rear; high-pressure lubricant research; truck ratings; allowable amounts of sulphur in gasoline; vapor-lock design requirements; applications of the wabblemeter to automobile, aircraft and industrial problems; and a host of other topics are now being discussed and applied to the consideration of engineering progress.

As predicted, the Summer Meeting, considered as an investment, is already paying big dividends.

Supplement to 1931 Handbook BY the time this issue of the S.A.E. JOURNAL reaches the members of the Society they will have received the July Supplement to the 1931 S.A.E. HANDBOOK containing the new and revised specifications adopted by the Society at the Summer Meeting in June. These specifications and their page references in the HANDBOOK and the Supplement, together with specifications that were cancelled, are listed in the first pages of the Supplement. A number of errata in the 1931 HANDBOOK are also noted, with their corrections.

All of the specifications in the Supplement will be included, according to their status, in the 1932 edition of the HANDBOOK when it is issued following the Annual Meeting of the Society next January. It is suggested that members mark all of the specifications in the 1931 HANDBOOK that have been either revised or cancelled, as the case may be, in accordance with the new specifications in the Supplement.

The Tentative Knock-Test Procedure LIKE rain following a drought is the announcement of the Detonation Subcommittee of the Cooperative Fuel-Research Steering Committee that it is answering the crying need of the industry for a standard method of conducting knock tests with a tentative recommended procedure. This is printed on page 164 of this issue.

This suggested practice is admittedly very preliminary and will no doubt be subject to rapid and continuous change in the course of future developments and further research work. However, the Committee is agreed that it is based upon the best knowledge at the present time, and it is courageously offered as an emergency measure, although the Committee is fully aware that, in spite of the widely commended progress that has been made since the Committee's inception, a great dearth of information still exists concerning the many factors which affect detonation testing.

18,500 Attend 178 Meetings IN 1930-1931, 178 meetings were held, exclusive of National meetings, by the 21 Sections of the Society, with an attendance of 18,500 persons. The great interest in the Sections' activities was shared by both members and non-members. The value of the meetings to both cannot be overlooked, nor can the value to the Society of the interest shown by the vast number of non-members.

Reducing Horsepower *and* Noise *of* Automotive Cooling-Fans

By A. D. Gardner[1]

Semi-Annual Meeting Paper

STATING the automotive cooling-fan problem as being constituted of the delivery of more air, decrease of fan horsepower, reduction of fan noise so that it is comparable with or less than other powerplant noises and the installation of the fan in a restricted space, the author describes the testing apparatus and method used in analyzing the subject. Fan speeds and the most effective number of blades are then considered, followed by analyses of fan diameter and pitch and curvature of fan blades. The manner in which air is discharged from the fan and the adaptation of a fan to an automobile are also discussed.

Following statements concerning the desirable number of fan blades and blade spacing, noise characteristics of fans are analyzed in detail as a preface to the author's consideration of means of reducing fan noise, and a summary listing the conclusions reached as a result of the study is appended.

INCREASE in automobile engine-size and engine-output have increased the demands on the cooling system. The radiator core must possess greater heat-dissipating capacity. The fan must supply more air. Power must be conserved to maintain car performance. As other engine noises have been greatly reduced, the fan has justly been criticized as being outstandingly noisy. Drastic steps taken in some cases to reduce fan noise have also reduced the cooling capacity. Hence the problem is to deliver more air, decrease fan horsepower, reduce fan noise so that it is comparable with or less than other powerplant noises and install the fan in a restricted space.

Hundreds of odd-shaped fans have been invented to solve this problem. Many ingenious devices for reducing fan horsepower and noise at the higher speeds, such as cut-outs, slipping clutches, double blades and the like, have been patented. Numerous attempts have been made to apply theories of airplane-propeller design to cooling fans, but it is not certain that the conditions of operation are sufficiently alike to permit this adaptation. It would simplify the fan designer's problems to be able to use scaled-down propellers for cooling purposes, and many data are available on propellers which the fan industry has not taken advantage of; but so long as fan blades must be made of thin-section sheet-metal stampings to be sold at prices which car manufacturers are willing to pay, the use of the propeller-type cooling-fan probably will be limited. The need is for a thorough investigation into the behavior, on and off the car, of the types of fan now in use and a consistent program of research and development aimed at their improvement. This constitutes the fan manufacturer's obligation to the industry.

Testing Apparatus and Methods Used

The characteristics of fan design and performance were determined by tests with the wind-tunnel set-up shown in Fig. 1, a type of tunnel commonly used for radiator testing, with no attempt made even to approximate conditions under an automobile hood; therefore, results are comparative only. The fan is mounted directly on the shaft of a cradle-type dynamometer having scales for recording the load and the necessary control panel and instruments. The fan blades are placed two-thirds in and one-third out of a shroud, whose inner diameter is 1 in. greater than the diameter across the blades. The rectangular-cross-section wind-tunnel has straighteners near the entrance cone. A radiator core

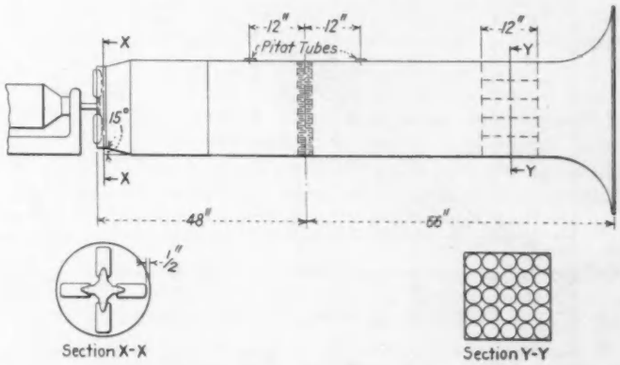

FIG. 1—WIND-TUNNEL USED FOR TESTING AUTOMOBILE FANS

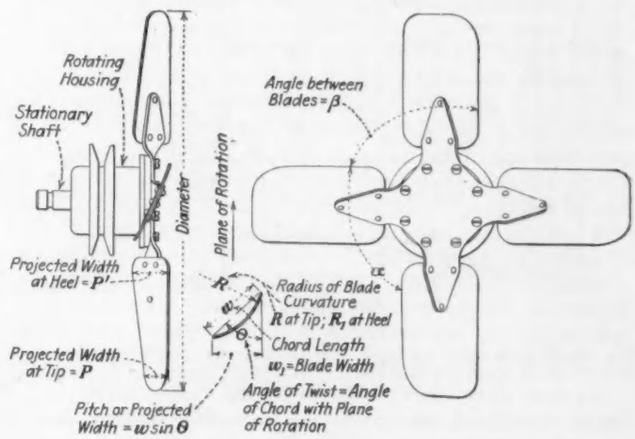
Rotating Housing
Stationary Shaft
Diameter
Plane of Rotation
Angle between Blades = β
Projected Width at Heel = P'
Projected Width at Tip = P
R
ω
Radius of Blade Curvature
R at Tip; R1 at Heel
Chord Length
ω1 = Blade Width
Pitch or Projected Width = ω sin θ
Angle of Twist = Angle of Chord with Plane of Rotation

FIG. 2—TYPICAL PROPELLER-TYPE FAN

[1] Chief engineer, Automotive Fan & Bearing Co., Jackson, Mich.

3¼ in. thick with ¼-in cells is installed between the fan and the entrance cone for all airflow and horsepower tests. Pressure readings were taken across the core. Airflow was measured with an anemometer by taking a traverse of a cross-section of the tunnel at the entrance. Fig. 2 shows a typical propeller-type fan.

Air Output and Horsepower

Concerning the air output of fans, Fig. 3 shows the relationship between fan speed and airflow for three medium-sized fans, having two blades, four blades and six blades, the fans being identical except for the number of blades. For a given fan, airflow varies directly as the speed and the curve is a straight line. The fans showed this straight-line characteristic over the speed range of these tests; but, at higher speeds, it is to be expected that the airflow of the six-blade fan would decrease because of interference between blades. Lack of power in the test set-up made it impossible to test the six-blade fan at speeds higher than those shown.

As to fan-horsepower requirements, Fig. 4 shows the relationship between fan speed and horsepower for the same fans shown in Fig. 3. For a given propeller-type fan, the horsepower varies theoretically according to the

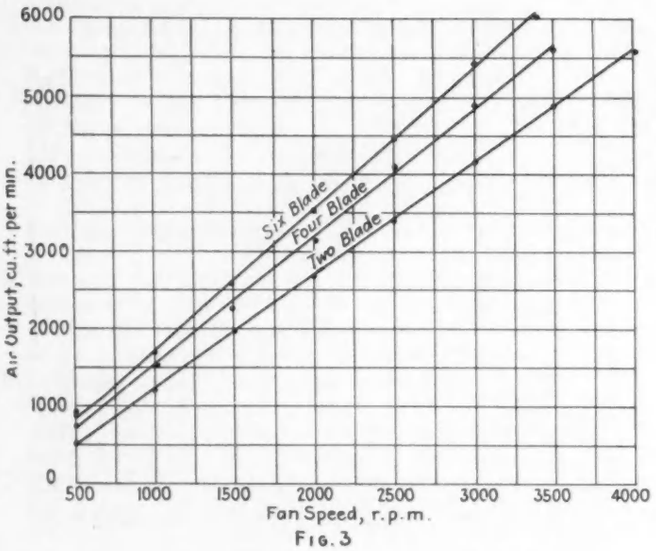

Fig. 3

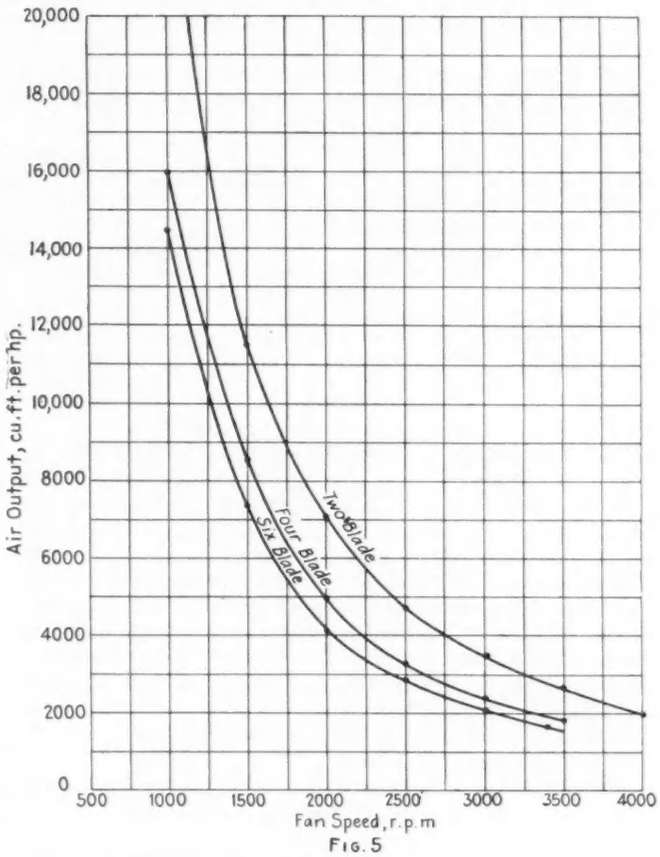

Fig. 5

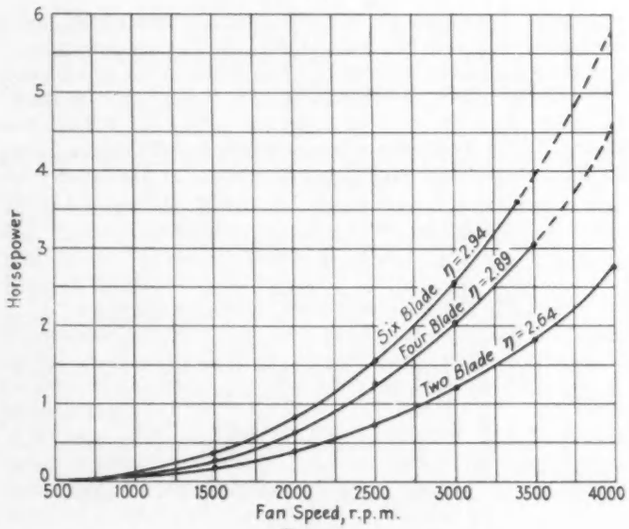

Fig. 4

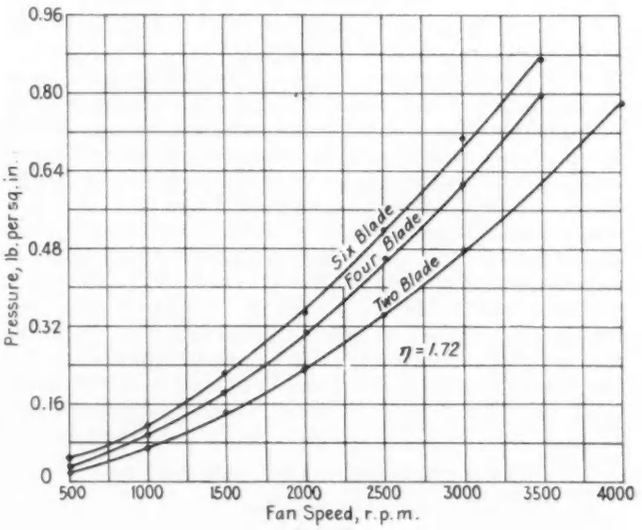

Fig. 6

Fig. 3—Relationship between Fan Speed and Airflow for Three Medium-Size Fans Having Respectively Two, Four and Six Blades, the Fans Being Identical Except for the Number of Blades

Fig. 4—Fan Speed and Horsepower Curves for the Fan Shown in Fig. 3

Fig. 5—Relationship between Fan Speed and Airflow per Unit Horsepower, the Curves Being Similar to Those in Fig. 4

Fig. 6—Pressure Drop through the Core Plotted Against Fan Speed

CURVES OBTAINED FROM AN 18-IN-DIAMETER FAN

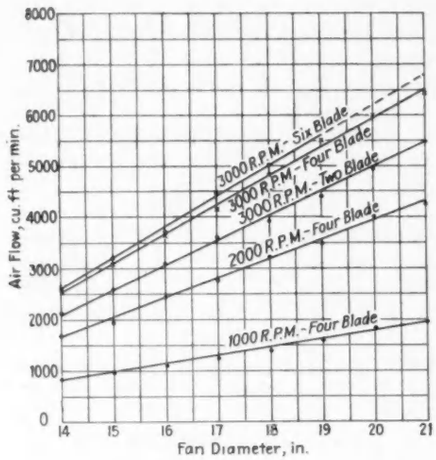

FIG. 7—RELATION BETWEEN AIR OUTPUT AND DIAMETER OF FAN

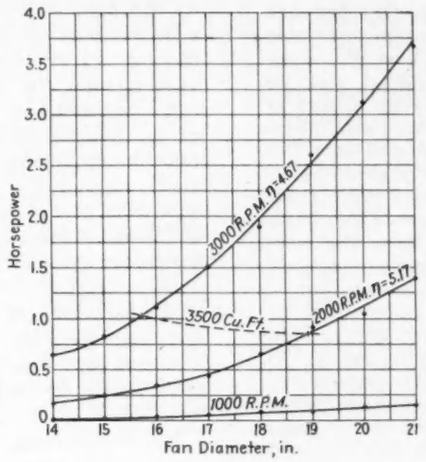

FIG. 8—HORSEPOWER AND DIAMETER RELATIONSHIP FOR A FOUR-BLADE FAN

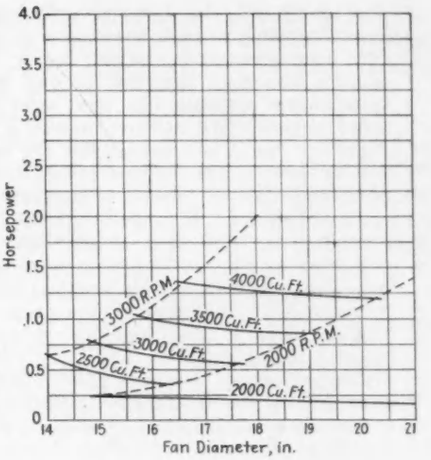

FIG. 9—EFFICIENCY-DIAMETER CHART FOR A FOUR-BLADE FAN

cube of the speed. The exponent in the curves of Fig. 4, instead of being 3, has values between 2.89 and 2.94.

The rate at which fan horsepower increases with the speed forms the basis for the fan designer's recommendations that, to use the minimum horsepower, the fan should be run as slowly as possible for a given installation and that other fan features such as pitch, blade curvature and spacing of blades be utilized to attain the airflow needed for adequate cooling. Horsepower requirements of fans vary also with the diameter; angle of twist; radius of curvature; shape of blade; angle between blades; number of blades; position of reinforcing rib; thickness of material; speed of impact of the airstream into the fan; size, number and position of slots in the blades and other features.

Fan Speeds and Number of Blades

Fig. 5 shows the relationship between fan speed and airflow per unit horsepower, the curves being similar to the horsepower curves in Fig. 4—since the airflow curves are straight lines—and have the same exponents. Fig. 5 shows that the minimum horsepower is used per unit of air delivered when the fan speed is low. These curves are a measure of fan efficiency, that is, of the output per unit input; the higher the curve is the higher is the efficiency. That all three curves slope downward toward the right indicates that the fan should be run as slowly as possible.

The lower limit of fan speed for any given installation preferably should be determined by the slow-speed, full-throttle cooling requirements; that is, by the cooling requirements for hill climbing or towing with wide-open throttle. If the fan is mounted and driven as a unit, its speed can be governed by the cooling requirements. If it is mounted on a water-pump or generator shaft, its speed must be such as to meet the requirements of these units. In general, these units are driven at higher rates of speed than is necessary for the most suitable fan to be driven to meet cooling requirements, so that a fan so mounted may not operate at its speed of greatest efficiency or it may be objectionably noisy.

Practically all present-day automobiles and trucks use fans having either two, four or six blades, but in several isolated cases three-bladed fans are used. The two-blade fan is most widely used on the smaller engines. What it lacks in airflow per revolution is compensated for by speeding it up, which is usually done by mounting it on the water-pump or generator shaft. Its efficiency is very good, but its air output limits it to the smaller installations.

This type of construction is well adapted to the smaller cars, since the fan blade can be made as a single stamping, which requires the minimum amount of material and labor and results in low initial cost. However, a number of disadvantages exist and the apparent saving may not always be justified when the undesirable features, such as horsepower consumption and noise, are taken into account. It is even possible, in many cases, to effect an over-all saving in the cost of the cooling system by using a fan having more blades to assure greater air delivery, and then to decrease the dissipating capacity of the core correspondingly to obtain a resultant saving in weight and cost which probably would more than offset the cost of the larger fan.

The four-blade fan is most widely used. It is economical of material when made either in the form of two crossed blades or as a spider with blades attached. Its low-speed air-delivery is better than that of the two-blade type. At high speeds its air delivery is well sustained without excessive blade interference and noise. The six-blade fan is used on the larger engines, especially where there is insufficient room for the greater diameter or projected width which would be required for equal airflow from a four-blade fan. In extreme cases six or even eight blades of large diameter, heavy pitch and abrupt curvature may be required, but these are seldom necessary in automotive installations.

A small-diameter six-blade fan having considerable projected width and driven at a rather high ratio can usually be replaced to excellent advantage by a four-blade fan of larger diameter running at a slower speed and having wide, flat blades. For example, the following report was made by the engineering department of a car manufacturer. It refers to replacing a six-blade 16-in.-diameter narrow-blade fan of 2-in. projected width by a four-blade 18-in-diameter fan having wider blades angularly spaced at 50 and at 130 deg. and of 1 11/16 to 1 in. projected width.

> The work we have done here has been chiefly concerned with reducing the horsepower which must be transmitted by the fan belt. As the fan develops

practically all the horsepower which the fan belt must transmit at high speed, our attention has therefore been directed to the fan itself. Most of our attention has been directed to our Model-8, but the information obtained has been used in the design of other models. We had on Model-8 a six-blade, 16-in-diameter fan. The total load on the fan belt with this fan at 4000 r.p.m. engine speed was approximately 14½ hp. It was found experimentally that equal cooling could be obtained with a four-blade 18-in-diameter fan and that at the same time the total power required could be reduced to aproximately 11 hp. Further work on this problem has shown that by increasing the diameter of the pump impeller ¼ in. and at the same time reducing the pump and the fan speed from a ratio of 1.37:1 to 1.24:1, that is, to crankshaft speed, we were able to obtain satisfactory cooling with the four-blade 18-in-diameter fan on an even larger engine than that on which the original six-blade fan was used. This decrease in fan speed gave a further reduction in fan power of 2¾ hp. so that the total reduction from the original six-blade 16-in-diameter fan to the new speed of the four-blade 18-in-diameter fan was 38 per cent of the total fan-belt horsepower. In our opinion these results show that a better design of fan can be made which will materially reduce the horsepower that must be used in driving it and at the same time give the desired cooling.

The foregoing facts form the basis for the recommendation that as few blades as possible should be used, the number being governed by airflow requirements for a given installation. Airflow, horsepower and efficiency are dependent on other design characteristics, as well as on number of blades, so that any installation is always a series of compromises.

Considerations of Pressure and Fan Diameter

This paper does not include results of tests for determining fan characteristics under various pressure conditions on either the suction or the discharge side of the fan, although pressure conditions in the engine compartment of an automobile have an important bearing on fan performance.

A cellular radiator-core 3¼ in. thick having ¼-in. cells was installed in the wind-tunnel on the suction side of the fan for all tests simply to make the results slightly more applicable to those obtained from the actual installation on the engine. Pressure drop through the core was observed for the two, four and six-blade fans of 18-in. diameter and 1½-in. projected width, whose characteristics already have been mentioned. Pressure drop is plotted against speed in Fig. 6. It will be noted that the pressure drop due to the two-blade fan bears approximately the same relationship to that of the four and the six-blade fans as do their respective air outputs, as shown in Fig. 3. The exponent of these curves is 1.72.

The next important variable to be considered in fan design is the diameter. Fig. 7 shows the relationship between air output and diameter of the two, four and six-blade fans having blades of 1½-in. projected width which were used in previous tests. The curves are approximately straight lines and indicate that the air output increases almost in direct proportion to the fan diameter, although it is generally assumed to increase as the square of the diameter or of the projected area. This test was made with blades of 14 to 21-in. diameter, operating up to 3000 r.p.m., which covers approximately the range of fan diameters as used on passenger-cars and trucks, excepting some of the larger-sized trucks. Further tests under various conditions are required to determine exactly the values of the exponent of the diameter.

Fig. 8 shows the relationship between horsepower and diameter for the four-blade fan having blades of 1½-in. projected width as used in previous tests. Theoretically, the horsepower should vary as the fourth power of the diameter; but, in these curves, the exponent lies between 4.7 and 5.1. No explanation is at

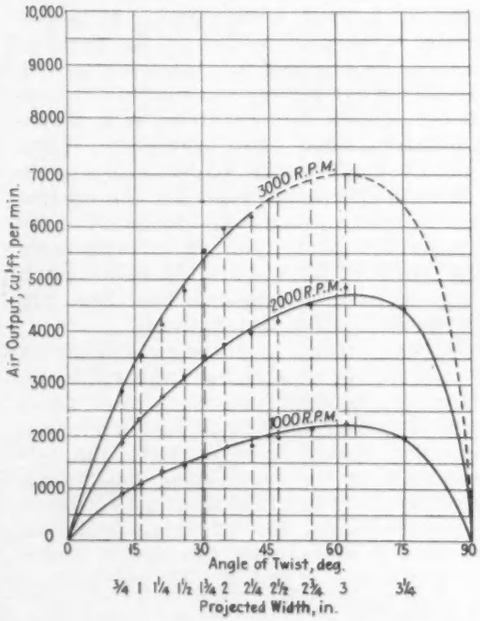

FIG. 10—RELATIONSHIP BETWEEN AIRFLOW AND PROJECTED WIDTH FOR A FOUR-BLADE FAN

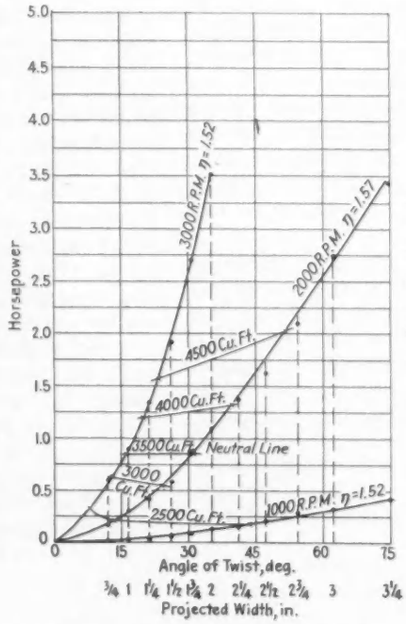

FIG. 11—VARIATION OF HORSEPOWER WITH PROJECTED WIDTH FOR THE SAME FOUR-BLADE FAN OF FIG. 10

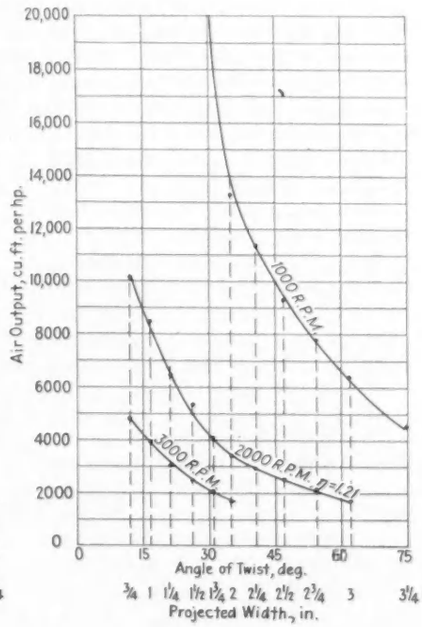

FIG. 12—EFFICIENCY VERSUS PROJECTED WIDTH PLOTTED FROM DATA OF FIGS. 11 AND 12

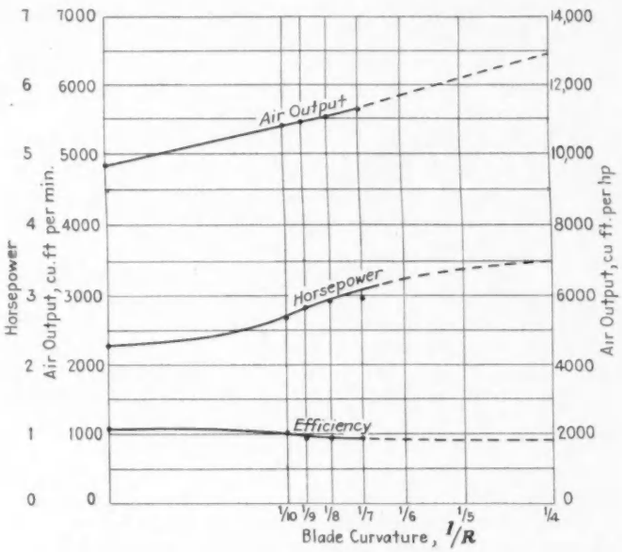

FIG. 13—RELATIONSHIP BETWEEN FAN-BLADE CURVATURE AND AIR OUTPUT, HORSEPOWER AND EFFICIENCY FOR A FOUR-BLADE FAN RUNNING AT 3500 R.P.M.

hand for this variation from the theoretical value. In fact, general experience indicates that these values are far too high. For instance, the fan designer is often confronted with the problem of increasing the efficiency of a small-diameter fan having blades of rather high projected width. This can almost invariably be accomplished at all speeds below 3000 r.p.m. by reducing the projected width somewhat and increasing the diameter by say ½ to 1 in., the blade width remaining unchanged.

Reducing the projected width of blades increases the efficiency, that is, the number of cubic feet of air per horsepower, along a curve whose exponent is 1.21 (See Fig. 12), which is a rather low value and a rather small gain in efficiency. Having increased the efficiency at this low rate, increasing the diameter decreases the efficiency along a curve whose exponent is 3.75, this value being computed from Fig. 8, or at a much higher rate, so that the net result should be a loss of efficiency if the exponents are correct. In actual practice, however, a gain in efficiency is almost always made.

Referring to the curves in Fig. 7, in which airflow is plotted against diameter, it is found that to deliver say 3500 cu. ft. of air per min. this four-blade fan with 1½-in. projected width of blade must be given a diameter of 15¾ in. if running at 3000 r.p.m.; or, a diameter of 18⅞ in. if running at 2000 r.p.m. Locating the point of 15¾-in. diameter on the 3000-r.p.m. curve of Fig. 8, horsepower plotted against diameter, and the point of 18⅞-in. diameter on the 2000-r.p.m. curve of Fig. 8, and connecting these points with a smooth curve, gives a curve showing the speed, diameter and the horsepower required to deliver 3500 cu. ft. of air per min. with this four-blade fan of 1½-in. projected width of blade. This curve is shown dotted in Fig. 8, and represents the well-known scheme of plotting three or more variables on one graph.

In the same way the curves for 2500, 3000 and 4000 cu. ft. can be determined. They are shown in Fig. 9. The 3500-cu. ft. curve slopes downward toward the right which indicates that, for this air delivery, the horsepower can be reduced by increasing the diameter of the fan and driving it at a lower speed. The same tendency is shown by the other curves of Fig. 9 and verifies actual experience.

Probably if the air delivery of this fan were increased to be greatly more than 3500 cu. ft. per min., the curve corresponding to those in Fig. 9 would slope upward toward the right. This would indicate an increase in horsepower with the diameter for a given airflow; that is, a decrease in efficiency. In this high air-output region there could be a loss of efficiency as the diameter was increased, which would explain the loss indicated by the exponent 3.75 of the efficiency curve computed from the horsepower curve of Fig. 8. In the region of low air-output, however, the efficiency increases as the diameter increases, which verifies actual experience; but it is still at variance with the exponent of the efficiency curve computed from Fig. 8, that is, the horsepower-diameter curve. Obviously, further investigations are required to reconcile these differences.

Pitch or Projected Width of Blades

By pitch of the blade is meant the projection of the blade along the axis of rotation. Neglecting losses, it represents the thickness of a disc of air which the blade slices off and displaces to the rear at each revolution. Projected width is the more accurate term. Fig. 10 shows the relationship between airflow and projected width, which is expressed in inches and in angle of twist; that is, the angle which the chord makes with the plane of rotation. The same 18-in-diameter four-blade fan with blades having a radius of curvature of 7 in. was used for this test as in previous tests. The airflow increases up to the point where the angle of twist becomes 64 deg., after which it decreases and becomes zero at 90 deg. since there is no axial displacement of air with blades perpendicular to the plane of rotation. In this position, the fan acts simply as a paddle. It churns the air but does not displace it

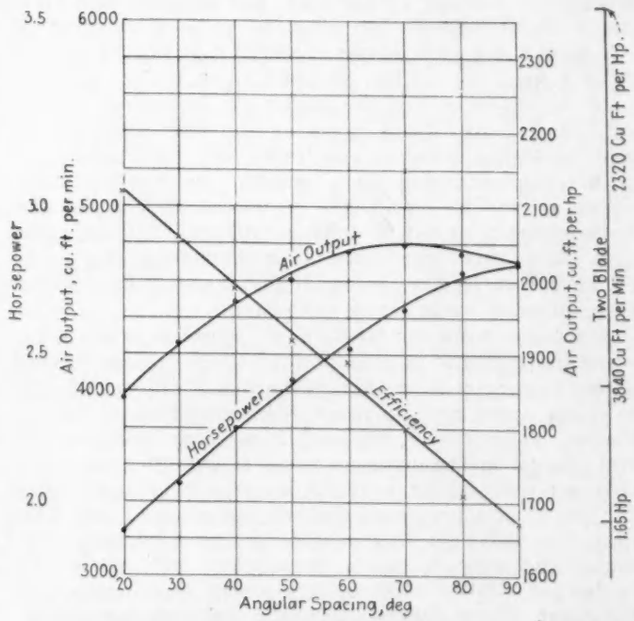

FIG. 14—AIR OUTPUT, HORSEPOWER AND CUBIC FEET OF AIR PER HORSEPOWER PLOTTED AGAINST ANGULAR SPACING OF BLADES FOR A FOUR-BLADE FAN RUNNING AT 3000 R.P.M.

axially. It consumes horsepower but delivers no air. The maximum airflow occurs at a pitch of 3 in. for a blade width of 3⅜ in. and a chord length of 3 21/64 in. Experience with this type of blade has shown that the airflow increases very slowly when the pitch is increased beyond about 2 to 2⅛ in., which corresponds to an angle of 40 deg. The curves of Fig. 10 verify this opinion, especially at the lower speeds.

Fig. 11 shows the variation of horsepower with projected width for the same four-blade, 18-in-diameter fan. These curves have an exponent of 1.52. While this fan delivers its maximum air-output at a pitch of approximately 3 in. or a chord angle of 64 deg., the horsepower curve shows the power consumption to be excessive at this pitch; that is, 0.3 hp. at 1000 r.p.m., 2.7 hp. at 2000 r.p.m. and 8.9 hp. at 3000 r.p.m.

Fig. 12 is plotted from the data of Figs. 10 and 11 and shows the variation between the number of cubic feet per horsepower, that is, the efficiency, and the projected width. These curves show why it is inadvisable to have the projected width up to the point of maximum airflow; that is, 3 in. or 64 deg. The number of cubic feet per horsepower at the projected width of maximum airflow is 6000 at 1000 r.p.m., 1600 at 2000 r.p.m. and 800 at 3000 r.p.m. In general practice it has been found that a projected width equal to about one-half the blade width across the chord gives a good compromise between air output and efficiency, forming a fairly quiet blade at the higher speeds. This gives an actual projected width of 1 11/16 in. for this blade and an angle of twist of 30 deg. The efficiency at this projected width is about 20,000 cu. ft. at 1000 r.p.m., 4200 cu. ft. at 2000 r.p.m. and 2100 cu. ft. at 3000 r.p.m. This compares very favorably with the efficiency at the point of maximum airflow and supports the conclusion that as small a projected width as possible should be used for an efficient fan at higher speeds as is consistent with the required air delivery at low speeds.

Referring again to Fig. 10, it is evident that to deliver 2000 cu. ft. of air per min., for instance, this four-blade 18-in-diameter fan must be given a twist angle of about 8 deg. if running at 3000 r.p.m.; or 13 deg. at 2000 r.p.m.; or 44 deg. at 1000 r.p.m. If the 8-deg. point is now located on the 3000-r.p.m. horsepower curve of Fig. 11, the 13-deg. point on the 2000-r.p.m. curve and the 44-deg. point on the 1000-r.p.m. curve and these points are connected by a smooth line, the resulting curve shows the speed, the projected width and the horsepower required to deliver 2000 cu. ft. of air per min. with this four-blade, 18-in-diameter fan. This curve, shown in Fig. 11, is simply a means of plotting three or more variables on one chart.

Since the curve for 2000 cu. ft. per min. falls off toward the right, it is evident that the minimum horsepower is required for this air output if the fan is run at a low speed and its pitch is increased up to 2⅜ to 2½ in. The curve for 3000 cu. ft. per min. is determined and plotted in the same way and shows the same tendencies; that is, its best efficiency is obtained if the fan is run at a low speed and with increased pitch. The curve for 3500 cu. ft. per min. is approximately horizontal and may be called the neutral line, while the curves for 4000 or 4500 cu. ft. per min. slope upward to the right. These curves show that, for the least horsepower consumption with this four-blade, 18-in-diameter fan, if the output desired is less than about 3500 cu. ft. per min. the fan should be operated at a low speed and be given considerable pitch. If the output desired is greater than about 3500 cu. ft. per min., the fan should be operated at a high speed and be given a smaller pitch. In this way these curves can be utilized by the fan designer to make intelligent compromises among the various factors entering into efficient fan-performance.

One of the most efficient types of blade developed for automobile cooling-fans is the so-called spiral blade, which has a rather high projected-width at the heel and a low projected-width at the tip. The radius of curvature at heel and tip may be different, usually being smaller at the heel. The spiral-type blade apparently fulfills the requirements of Fig. 11. The heel of the blade has a high projected-width, but a low velocity with respect to the air, thus falling within the zone of efficient operation below the neutral line or horizontal curve of 3500 cu. ft. per min. shown in Fig. 11. The tip of the blade has a low projected-width and a high relative speed, thus falling within the zone of efficient operation above the neutral line. This verifies experience which has proved the spiral blade to be very efficient. It is about as close to airplane-propeller design as can readily be obtained by the use of the thin-section stampings which the fan designer is forced to adopt for economic reasons.

Blade Curvature and Unequal Spacing

Fig. 13 shows the relationship between fan-blade curvature and air output, horsepower and efficiency for a four-blade, 18-in-diameter fan running at 3500 r.p.m. Lack of power limited the scope of the tests; but, in general, the relationships are as shown. Blade curvature is expressed as $1/R$, the reciprocal of the radius of curvature in inches, so that the flat blade of infinite radius could be shown; it appears at zero abscissa since $(1/R)=0$. The airflow increases approximately in a straight line with the change in curvature from a flat blade to one having a radius of about 4 in. The horsepower increases slowly at first, then more rapidly and finally the curve flattens out.

The number of cubic feet per horsepower is highest for a flat blade, slowly drops off, then apparently becomes almost constant at the more abrupt curvatures of 5-in. and 4-in. radii. The constancy is to be expected because the curvature becomes so abrupt that the air will not follow the surfaces of the blade; hence the projected width or other blade characteristic, rather than the degree of curvature, seems to determine the airflow. It is as if a blunt object were whirled through the air, displacing air due to its general dimensions, rather than to the exact curvature of its surfaces.

The flat blade has been used to a limited extent. It is efficient, but its air output is low; therefore, where air requirements are high, it becomes necessary to use a curved blade. In these tests the blade curvatures are arcs of circles. Blades in actual use are given many different kinds of curvature to meet special purposes, including spiral, arc and spiral, a flat on the leading or the trailing edge, rolled edge, thick section and the like. Many of these blades have merit, but too many variables enter into their design to permit them to be covered herein. It is believed that considerable gains in fan efficiency can be made as a result of research and development work on fan-blade curvature, as well as on the number, size and position of slots in the blade.

The idea of spacing the blades at unequal angles was developed as a means of reducing apparent fan noise

by blending its sound with the other engine sounds. But its air-output and horsepower characteristics show that it has possibilities from the standpoint of efficiency.

In Fig. 14, air output, horsepower and cubic feet of air per horsepower are plotted against angular spacing of blades for a four-blade 18-in-diameter fan having a 1¾-in. projected-width and tested at 3000 r.p.m. The air output increases somewhat from 90 to about 70 deg., then decreases as the angle between the blades becomes more acute, probably due to the interference of the leading blade with the functioning of the trailing blade. The horsepower drops as soon as the angle between the blades is decreased from 90 deg., but at a faster rate than the airflow, so that the efficiency curve rises steadily; but it does not reach the efficiency of a two-blade fan whose characteristics are shown at the extreme right.

These curves are fairly typical of this type of fan, except that in some cases the efficiency curve drops more slowly; but it apparently never slopes downward toward the left in the range of automotive installations. This new fan development is being produced with angles of 50, 70, 75 and 76 deg. between the blades of four-blade fans and angles of 40 to 80 deg. between the blades of a six-blade fan. Seemingly, it is at least as effective as the best of the conventional types of construction.

Blade Width Considered

One of the means which has been extensively used in reducing fan horsepower is to increase the blade width. To ascertain just how effective this method is, tests were made with two four-blade, 18-in-diameter fans which were identical except for width of blade. The blades on one fan were 3 in. wide; on the other they were 4 in. wide, which is about the range used for automobile cooling-fans.

Fig. 15 shows the air output of these two fans at 2500 r.p.m., plotted against the projected width in inches. For the lower values of projected width, from 1¼ to 1⅞ in., the output of the narrower 3-in. blade was greater because the angle of twist was greater to attain the same projected-width. Above a 1¾-in. projected-width, the 4-in. blade showed greater air output. Fig. 16 shows the horsepower consumption of the two blades. The narrower blade required greater power because it was twisted at a greater angle with the plane of rotation than was the 4-in. blade to attain the same actual projected-width. This verifies the curves of Fig. 11.

Fig. 17 shows the relationship between cubic feet per horsepower and projected width, the wider blade showing the greater efficiency. This verifies actual experiences and is the basis for the recommendation that fan blades should be as wide as practicable to attain the highest efficiency and minimum noise.

Fan Discharge Analyzed

Another fan characteristic about which very little information has been made available is the manner in which air is discharged from a fan. Even in free air the discharge is anything except the commonly accepted idea of a solid stream of air moving away from the fan at a more or less uniform velocity. To obtain some idea of what happens, a four-blade 18-in-diameter fan having a 1½-in. projected-width was mounted on the end of the dynomometer shaft in free air. The velocity-measuring portion of a pitot tube was used to take readings in inches of water directly back of the fan and at intervals of ½ in. across the horizontal diameter. The fan was run at 1000 and at 3000 r.p.m. Additional runs were made with a fan having a 1¾-in. projected-width. Using a base line parallel to the plane of the fan, the values of the velocity pressure were plotted as shown in Fig. 18.

Several surprising features are indicated. The airflow at the center of rotation is toward the fan, and that over the outer one-third of the blade is also toward the fan. The flow at the tips of the blades is radially inward toward the fan. The greater the air-

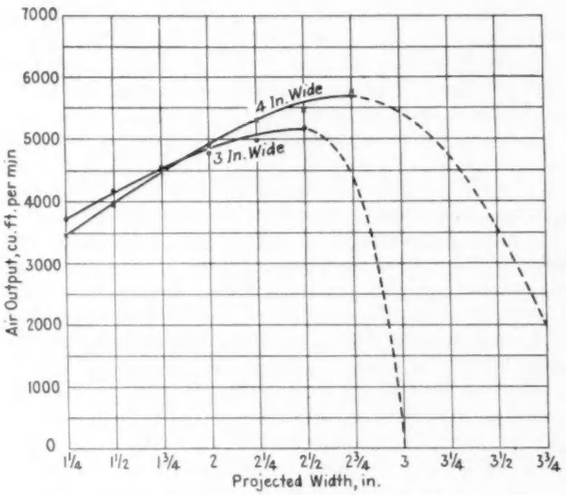

FIG. 15—BLADE WIDTH VERSUS PROJECTED WIDTH FOR A FOUR-BLADE FAN RUNNING AT 2500 R.P.M.

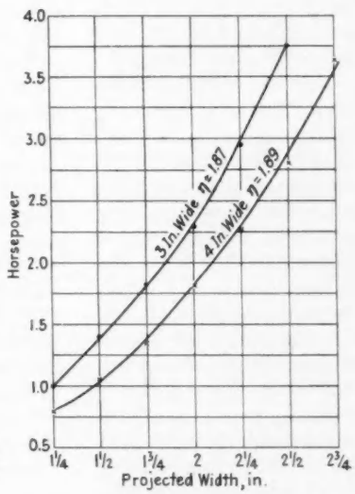

FIG. 16—HORSEPOWER-CONSUMPTION OF A FOUR-BLADE FAN HAVING BLADES 3 IN. WIDE COMPARED WITH ONE HAVING BLADES 4 IN. WIDE

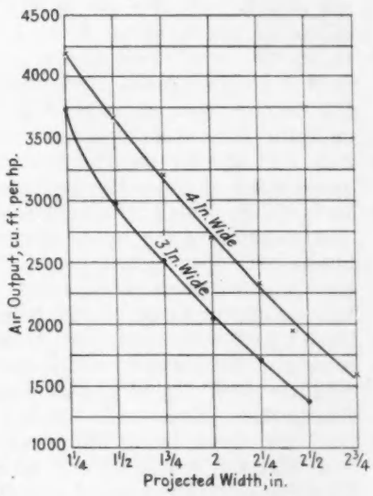

FIG. 17—RELATIONSHIP BETWEEN CUBIC FEET PER HORSEPOWER AND PROJECTED WIDTH FOR BLADES 3 IN. AND 4 IN. WIDE RESPECTIVELY FOR A FOUR-BLADE FAN RUNNING AT 2500 R.P.M.

flow away from the fan over the inner two-thirds of the blade is, the greater is the flow toward the fan over the outer one-third. Obviously, here is a field for extensive research and development work on the part of the fan engineer to alter the discharge characteristics of the fan by changes in blade design so as to increase both the air output and the efficiency.

Adapting the Fan to the Car

Having determined the specifications of a satisfactory fan when considered by itself, let us investigate what its performance may be when it is installed on the engine. To maintain its potential air delivery, the fan should be located so as to have free flow of air through the core to it and free discharge of air from it. This can be attained to the greatest extent in most cases by mounting the fan as high as possible on the engine, where air discharge from the fan is least restricted because the air flows over the top and sides of the engine and out from the engine compartment through side-pan openings and hood louvers. Exit openings from the engine compartment should be as large and as numerous as practicable. Hood louvers should be located so as to permit exit of air and prevent entry to the engine compartment. Obviously, any air which enters the engine compartment elsewhere than through the radiator core vitiates the cooling capacity to that extent. If the air outlets from the engine compartment are limited in area, the resistance causes a pressure to be built up, which results in decreased fan-output.

Air output of the fan is affected by the position of the blades with respect to the core. If the distance from the core to the blades is as great as say 2½ to 3 in., air leaving the fan may form eddies past the tips of the blades and enter the fan again. Air may be drawn through the forward louvers in the same way. A shroud could be used to advantage to overcome these difficulties partly. Even with the fan only ½ to ¾ in. from the core, there is doubtless a considerable loss of airflow through the core due to the counter-flow eddies forward past the tips of the blades and into the fan from the front.

Air Requirements of Cooling System

With the long straight-eight engines now being used, the fan is likely to be placed too close to the core. From the standpoint of airflow, this means that the flow through the core is likely to be localized into the projected area of the fan. If the diameter is small, little air may be drawn through the far corners of the core, or a reversal of flow through the corners may actually occur. As regards the volume of air which the fan should draw through the radiator core to provide adequate cooling, tests were made on a car running on the rolls of a chassis dynomometer at 30 m.p.h. The average airflow through the core with shutters wide open was 1000 to 1100 linear ft. per min. This car was considered to be cooled somewhat better than is the average car.

Too little information has been made available by the car manufacturers' engineering departments as to the relationship between cooling capacity and airflow under various conditions of car operation, so that it has been impossible to arrive at a general expression for the effect on cooling capacity of the output of a fan whose general characteristics are known from laboratory tests. Some cooling-system engineers maintain that the capacity of the cooling system to dissipate heat increases approximately as the increase in airflow from the fan; others, that after a certain airflow has been reached, additional airflow has little or no effect on cooling capacity. Considerable difference of opinion exists also on whether or not a fan is required for adequate cooling at the higher car-speeds.

In the early days of the industry, the heat output from the engine to the cooling water was comparatively low. Radiator cores apparently possessed ample dissipating capacity. The fan in most cases was driven by a flat belt, at least for a few hundred miles after each belt adjustment. The remaining portion of the time the fan probably exerted little effect on the cooling of the engine. The idea, therefore, became prevalent that fans were not needed except at the lower speeds and this idea has been retained by some up to the present. It may be said that, except for cold-weather operation, air output of the fan must be maintained throughout the full speed-range if adequate cooling is to result. My experience has been that the difference in radiator top-of-the-tank temperature with a fan and without a fan amounts to 5 to 20 deg. fahr. at top speed, even when air impact against the core is at the maximum value.

No information is available on the actual horsepower consumed by the fan as the car is driven along the road, although numerous tendencies are present. The fan speed tends to decrease due to belt slippage, but an opposing tendency to speed up exists, due to impact air from the car's motion. Several devices are being developed to measure the actual fan horsepower while the car is in motion and it is hoped that this important information will soon be available.

In automobile practice, fan speeds vary from about 0.8 crankshaft speed for the large six-blade fans to about 1.4 times crankshaft speed for the smaller two and four-blade fans. A very commendable tendency exists on the part of car manufacturers' engineers to reduce the higher ratios to eliminate fan noise, to reduce fan horsepower and to increase efficiency.

In general, it can be said that the air-delivery requirements of automobile cooling-systems can be met with a properly designed and located fan running not faster than at approximately crankshaft speed. This represents, for the present at least, an ideal we are striving to attain. It cannot be fully attained where radiator frontal area is limited, where there is insufficient room between engine and core, where air exit from the engine compartment is insufficient or where fan size is reduced by interferences with stationary parts.

Desirable Number of Fan Blades

The test results already discussed indicate that, for efficiency, as small a number of blades as possible should be used. Obviously, two is the minimum and a two-blade fan ordinarily will not cool a medium or a large-size engine, even with high fan-ratios. In choosing between four and six blades, it is preferable to use four blades whenever possible. However, in some installations, there is so little space between the radiator and the engine, and the fan diameter is so limited by interferences, that it becomes necessary to use six blades to attain even reasonable cooling capacity.

If the fan is mounted high on the engine, the diameter may be limited only by the radiator side-members and the top tank or the upper water-hose connection. A lower mounting of the fan may reduce its diameter due to interference of blades with vibration

damper, crankshaft pully, generator pulley or gearcase cover. Any reduction in diameter makes it necessary to speed up the fan to obtain the same degree of cooling, which results in increase in horsepower and loss in efficiency as shown in Fig. 5. With the small-diameter fan in a low position, there remains above the sweep of the blades a considerable portion of the core of the high, narrow radiator which is so prevalent at present, and it is sometimes difficult to induce an even and sustained airflow through this upper portion of the core. Large-diameter fans cover a greater area of the core, bringing in the corners and inducing a higher average rate of flow through the core.

The effect of increased projected-width, as well as greater blade-curvature, is to increase the flow of air in the same manner as in the wind-tunnel. But the areas through which the air must pass after leaving the fan change so abruptly and the obstructions in its path are so varied in size, shape and position, that it is impossible to know just what happens. Attempts made to measure airflow at various places under the hood have not been particularly successful so far as is known. However, the direction of discharge of the air from the fan can be controlled to a very limited extent by various changes in fan characteristics, as shown in Fig. 18; therefore, gains might be made in some cases by making use of these facts.

Fan Position Induces Noise

Besides the noises that exist in the fans themselves, the position of the fan on the engine may induce others. It has been found that placing the fan too close to the core increases the fan noise. Experience on a large number of cars of all types indicates that the fan blades should not run closer to the rear face of the core than about $\frac{5}{8}$ in. at the bottom or nearest point. In some cases fans run closer to the core than this; but, in such instances, extra precautions usually are necessary to prevent excessive noise. Certain types of radiator core induce more fan noise than others.

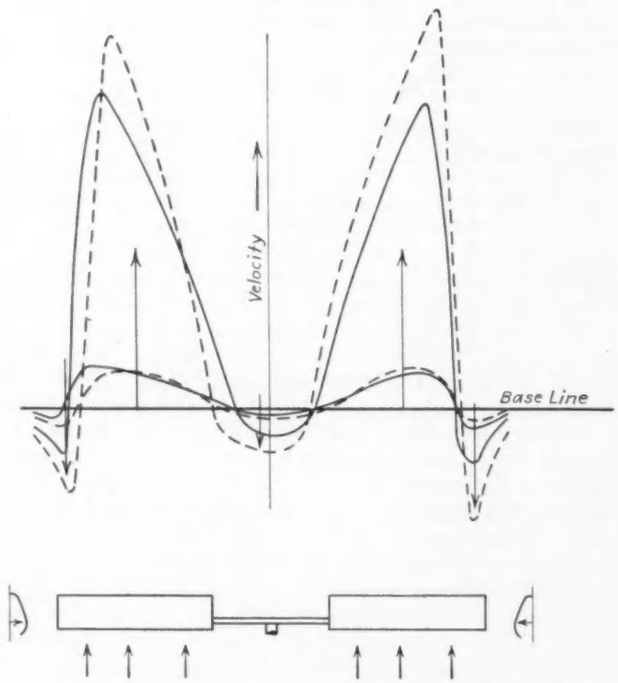

FIG. 18—DISCHARGE CHARACTERISTICS FOR A FOUR-BLADE FAN

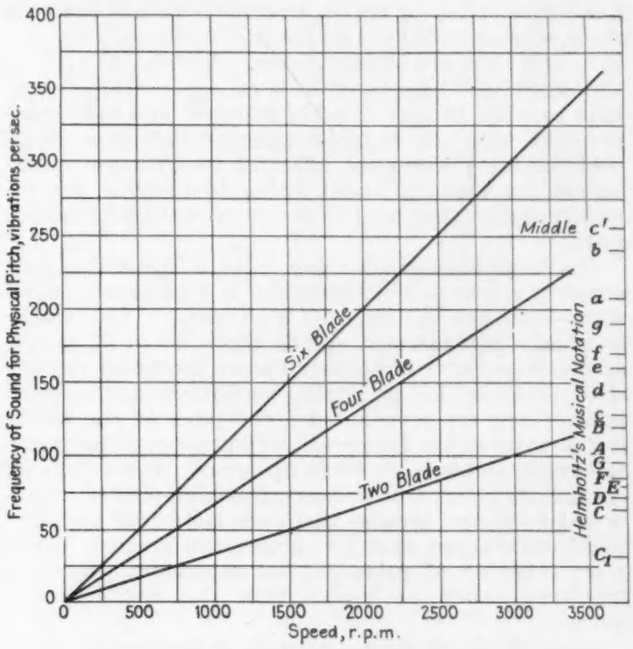

FIG. 19—PITCH OF FAN SOUNDS

Fan blades should not run too close to vibration dampers, crankshaft pulleys and the like. If the blades sweep through a narrow pocket between the damper or gearcase cover and the core, it may be found preferable to run the blades closer to the latter than to the former. Any flat surface near the fan which could vibrate as a diaphragm tends to accentuate fan noise. Fans usually seem more noisy when radiator shutters are closed than when the shutters are open. A fan running too close to the open end of a horn, or a funnel, might set up a condition of resonance which would be objectionable. If the tips of the blades pass too close to the overflow pipe, the radiator hose, the fan belt or the pulley, noise may result.

Noise Characteristics of Fans

Fan noises or sounds that ordinarily cause concern can be classed as whine, roar, flutter, whir and beat. No attempt is made to differentiate between noise and musical tone. The fan sound or noise is made up of many components which are themselves simple tones, yet the fan noise possesses sufficient regularity of vibration so that its place in the musical scale can be recognized and identified as to pitch or frequency. Using S as a symbol for fan speed in revolutions per minute, the frequency of the sound given forth from a two-blade fan has been observed to be $2S/60$ vibrations per sec.; that for a four-blade fan, $4S/60$ vibrations per sec. or twice as great; and that for a six-blade fan, $6S/60$ vibrations per sec. The ratio of frequencies is the ratio of the number of blades for a given speed of rotation; or the ratio of the number of revolutions per minute for a given number of blades. (See Fig. 19.)

For example, a two-blade fan was observed to emit, at about a speed of 3600 r.p.m., the tone *B* in the bass clef which results from 120 vibrations per sec.; a four-blade fan emitted, at about 3600 r.p.m., the tone *b* in the bass clef which results from 240 vibrations per sec.,

one octave higher on the scale; and a six-blade fan gave forth, at about 2560 r.p.m., the tone middle c^1 which results from 256 vibrations per sec. (See Fig. 19.)

Observations have been made on automotive cooling-fans between 16 and 19 in. in diameter and these relationships hold. It is to be expected that they would hold for other sizes, the effect of the increase in diameter, or blade-tip speed, being to increase the intensity, rather than to alter the pitch of the sound given forth.

The most objectionable fan noise is the whine produced by a four or a six-blade fan at high speeds, or by a two-blade fan at extremely high speeds. This whine is usually noticeable at speeds above 45 to 55 m.p.h. on deceleration, or at slightly higher speeds on acceleration if noises due to intake, combustion and exhaust systems are not pronounced. The pitch of the whine is a function of the fan speed; its intensity, or loudness, apparently depends on blade-tip speed. When fans in general are referred to as noisy, this high-pitched whine is usually meant because there are more four and six-blade installations than two-blade; and because, for a given intensity of noise, the ear designates the high-frequency sound as louder than the low-frequency sound.

When two-blade fans are used, they may be fairly quiet at low and medium car-speeds; but, as they are usually driven at rather high ratios, the two-blade noise is usually evident at the higher car-speeds. It may be described as a low-pitched roar as contrasted with the high-pitched whine of the four or the six-blade fan. In fact, it is one octave lower in pitch than the whine of the four-blade and a double octave lower than that of the six-blade fans.

Blade Flutter and Beat Noises

In some cases in which blades have insufficient rigidity, they may flutter or vibrate back and forth at right angles to the plane of rotation. This fluttering may be aggravated when the fan is mounted low in front of the engine so that the blade, in passing through the lower part of its path, delivers but little air and is, therefore, not subjected to bending and torsional stresses from the air pressure on its surface. During the upper part of the blade's path, however, the blade does deliver air and is subjected to these stresses, which tend to draw the blade ahead as well as to flatten out its curvature. The blade, therefore, is subject to the maximum stress and resultant deflection, and to the minimum or even reversed stress and deflection, once each revolution. The frequency of the imposed stress and resultant flutter is, therefore, the same as that of the fan whine or road; that is, $NS/60$ vibrations per sec., where N represents the number of blades and S the fan speed in number of revolutions per minute.

Fortunately, the natural period of vibration of the size and type of blade commonly used on automotive cooling-fans is very small; that is, the frequency is much higher than the frequency of the impulses that cause fluttering. Resonance between the two vibrations is therefore not likely, which makes amplification of noise highly improbable. The natural frequency of vibration due to bending of a fan blade 8 in. long and 3 in. wide, constructed of No. 14 United States Standard gage 0.078 in. thick, was calculated and found to be 6160 vibrations per sec. The pitch of the fan whine of a six-blade fan at a speed of 4000 r.p.m. would be 400 vibrations per sec. and of a four-blade fan, 266 vibrations per sec., which shows that the sounds differ widely in pitch. When blade fluttering is present, it can usually be identified as an air impact or "blatting" noise of about the same pitch as the other fan noises. It is best heard from in front of the standing car when the engine is raced.

When a fan having rather flat, wide blades is given a rather high projected-width, it may emit a whirring sound which seems to be a combination of the sound of air leaving the blade with the rush of air through the shutters, core and hood louvers, and the resultant sound more or less subdues the high-pitched whine of the fan blades. Not all set-ups give this whirring sound even when large volumes of air are moved; but wherever such a sound can be obtained, it is much less noticeable than is the typical fan whine. This sound is very similar to the sound of the air rushing past an open car-window and is seldom considered objectionable.

Another fan noise that has been found objectionable is the "beat," in which the sound builds up to the maximum, fades out and then increases again, at a regular rate for a given fan and car speed. This beat seems to be caused by interference of sound waves whose frequencies differ slightly. The frequency of the beat equals the difference of frequencies of the two sounds producing it. Increasing the intensity of either noise increases the intensity of the beat; elimination of either noise silences the beat. This beat is usually blamed to the fan because it usually disappears if the fan is removed. The beat could be eliminated as surely by silencing the second source of interfering sound. On most cars which show this phenomenon, the frequency of the beat usually increases as the car speed increases, showing that the second source causing the beat is of higher frequency than the fan sound and that the increasing frequency of the fan sound as the car speed increases is approaching the frequency of the other source. The frequency of the beat becomes so high at higher car-speeds that it becomes a continuous sound as the frequencies of the sources become equal to each other.

Reducing Fan Noise

Let us now consider the means of reducing and otherwise rendering less objectionable the various fan noises already discussed. The most obvious and the simplest way of reducing fan whine is to decrease the speed of rotation. The lower speed reduces the pitch of the noise, so that it is not usually heard as a whine until a higher car-speed is attained. When the rotational speed is reduced, the tip speed is reduced proportionately and this reduces the intensity or loudness of the sound. Unfortunately, it is not always feasible to reduce fan speeds on account of loss in cooling capacity, so that other measures are usually necessary to eliminate whine.

A wide blade tends to substitute whir for whine, the former noise usually being considered as entirely satisfactory. Whenever whir can be substituted for whine, the problem may be considered as fairly well solved. A flat blade changes the direction of airflow across the blade gradually and has the same characteristic whir as a wide blade. For a given speed, diameter and blade width, the less curvature a blade has, the quieter the fan is, usually. Exceptions to this rule, however, usually apply to the type of blade having spiral or other compound curvature.

Two-blade roar can be reduced by slowing down the

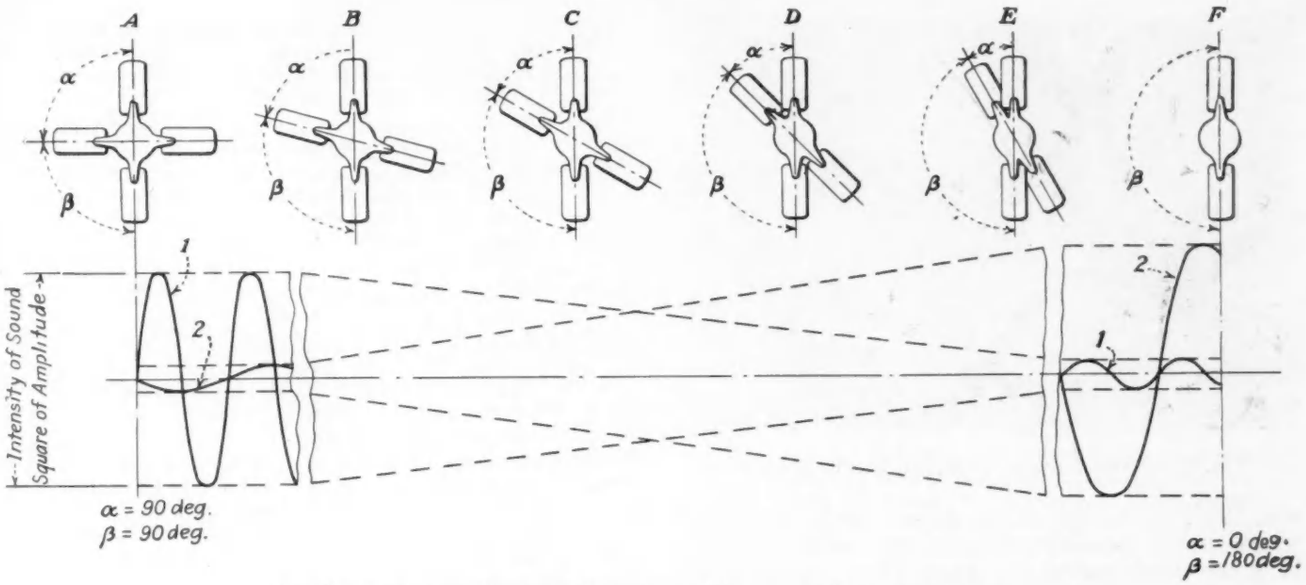

FIG. 20—EFFECT OF ANGULAR SPACING OF BLADES ON RELATIVE INTENSITIES

fan. If cooling suffers too much, a four-blade fan can be used and driven at a much lower speed. The increased airflow of the four-blade fan can be used in some cases to give better cooling with the same radiator core, or to reduce the core capacity and retain the same cooling as before.

Fan-blade flutter is not prevalent, since precautions are taken by fan manufacturers to make the blades stiff to avoid failure due to fatigue from vibration. Whir is greatly to be preferred to whine or roar and would hardly be called objectionable on most installations. Since it is an air sound, reducing the volume of air handled by the fan reduces the whir, but at the expense of cooling.

The beat can be eliminated by adjusting the frequencies of one of the two sources, whose slight difference in frequency causes the beat, so that they are exactly the same. This is most easily done by changing the ratio of fan speed to crankshaft speed by changes in pulley diameter. The fan-pulley diameter can be changed sufficiently so that the beat is not in evidence in the driving range of the car. The frequency of the beat seems to be very sensitive to slight changes in pulley size, it having been possible in several cases to move the beat from about 55 m.p.h. up out of the driving range of the car by a change of only 1/16 in. in pulley diameter. In some cases, with a tight fan-belt, there is no evidence of beat, while a slackening of the belt sufficient to lower the fan speed causes a slight beat.

Angular Spacing of Fan Blades

Applying the foregoing remedies is almost always helpful, but a few cases have been encountered where fan noise was not eliminated nor even reduced to passable proportions by these measures. On such installations, there seemed to be no difference in loudness or intensity of fan noise between what had proved to be a very noisy fan on other installations and a quiet fan, one whose characteristics were eminently satisfactory. The fan and the parts surrounding it seemed to comprise an acoustical set-up which was but little affected by changing from one fan to another of the same general type.

Since an appreciable reduction in intensity of fan noise appeared unlikely, and because the pitch or frequency of the sound was determined by the speed of rotation and the number of blades which, in turn, were determined from cooling requirements and could not be changed in this installation, an attempt was made to alter other noise characteristics of the fan so that, even if the intensity were not decreased, perhaps the noise could be made to blend in or merge with the other powerplant noises at the speeds and under the operating conditions where it has been outstanding. This was accomplished by varying the angular spacing of the fan blades about the axis of rotation as in Figs. 20 and 21.

In Fig. 20 at *A*, with an angle of 90 deg. between adjacent blades of a four-blade fan, the sound wave of four-blade frequency is represented by Curve 1 and that of two-blade frequency by Curve 2. It is evident from Curve 1 that the four-blade whine is the dominant sound at 90-deg. blade-spacing. As the angle α in Fig. 20 is decreased from 90 deg. as shown at *B*, *C*, *D* and *E*, the intensity, or loudness, of the four-blade whine gradually decreases and the intensity of the two-blade roar gradually increases until, at F, where angle α equals 0 and angle β equals 180 deg., the two-blade roar becomes a maximum and the four-blade whine becomes negligible. For positions *A*, *B* and *C*, the higher-frequency four-blade whine is dominant; and for positions *D*, *E* and *F*, the lower-pitched two-blade roar becomes dominant. By varying the proportion of these two components which, with others, make up the fan noise, it is possible to merge or blend-in the fan noise with the other engine noises, such as those emanating from the inlet manifold, exhaust manifold, muffler, combustion-chamber and front-end drive so that, to the observer, the apparent noise is greatly reduced.

In some instances, angular spacing is effective to within 1 deg.; in others, a change of 5 deg. or more is necessary to make a noticeable difference in the extent to which the fan noise blends-in with the other noises.

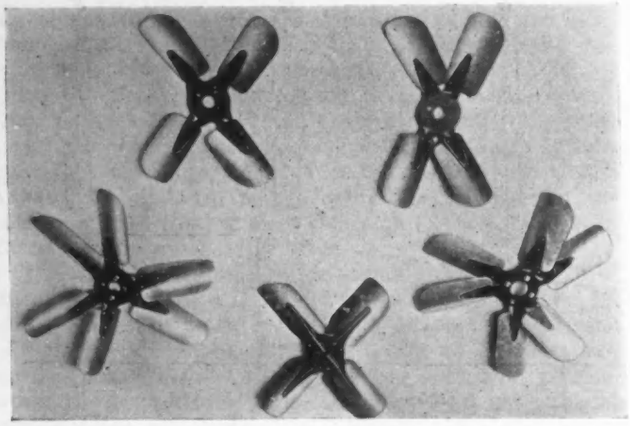

FIG. 21—FANS HAVING UNEQUAL BLADE-SPACING

Fig. 19 shows the four-blade whine to be in reality the octave of the two-blade roar, and the six-blade whine to be the double octave.

In applying the foregoing remedies to any given installation, the first step is to design as quiet and efficient a blade as possible to deliver the required volume of air. This having been done, the best angular setting of the blades is determined as a final step in noise elimination.

Summary

The foregoing tests represent only a very slight beginning in the considerable amount of research and development work which is necessary to develop cooling fans to the point at which their characteristics are thoroughly understood and the maximum airflow can be attained with minimum horsepower and the least noise. The following conclusions may be drawn:

(1) Air output increases directly as fan speed.

(2) Horsepower increases at a rate slightly less than the cube of the fan speed.

(3) The fan should be driven as slowly as possible, the lower limit being determined by low-speed, full-throttle cooling-requirements. Best practice indicates a ratio not higher than 1:1 with the crankshaft.

(4) Four-blade fans possess advantages over either two or six-blade, for all except the larger installations.

(5) The pressure drop across the core on the suction side of the fan varies at a rate slightly below the square of the fan speed.

(6) Experience indicates the advisability of using as large a fan diameter as is practicable. Some of the theoretical considerations are at variance with this practice.

(7) For low air-outputs, efficiency is increased by increasing the projected width and reducing the speed. For high outputs the efficiency is appreciably less than for low outputs, but its value can be increased by decreasing the projected width and operating the fan at a higher speed.

(8) The so-called spiral type of fan blade has proved to be very efficient.

(9) The flat blade is very efficient, but it lacks air output. On the other extreme too-abrupt blade-curvature defeats its own purpose since the air will not follow the sudden changes in direction of the surface.

(10) Fan blades should be as wide as practicable to attain highest efficiency and minimum noise. For automotive installations 4 in. is about the maximum width. Blades wider than 4 in. tend to vibrate and flutter.

(11) In adapting the fan to the car, as many as possible of the desirable characteristics should be retained. This can be accomplished in part by high mounting, free air-exits from the engine compartment, properly located louvers, fairly positive fan-drive, ample clearance with stationary parts and about ⅝ to ¾-in. clearance from the radiator core.

(12) Fan noises can be definitely located on the musical scale. They have frequencies of $NS/60$ vibrations per sec., where N is the number of blades and S the fan speed in revolutions per minute.

(13) The frequency of the fan sound depends on the number of blades and the speed. The loudness depends on the tip speed, other things being equal.

(14) Fan noise can be reduced by the means discussed. It can be blended-in with other engine noises by varying the angle between the blades, which varies the proportion of four-blade whine and two-blade roar.

(15) To obtain the best results for any given installation, run the fan as slowly as possible with as few—usually four—wide, flat blades of as slight projected-width as possible and have the diameter as great as is practicable. To obtain more air, increase the projected width, or the width or the curvature. Increase the speed only as a last resort.

Airplane Fuel-Line Temperatures[1]

By O. C. Bridgeman[2], C. A. Ross[3] and H. S. White[4]

19th National Aeronautic Meeting Paper

THE VAPOR-LOCKING temperature of a gasoline decreases about 2 deg. fahr. for every 1000-ft. increase in altitude, while the atmospheric temperature normally decreases 3.6 deg. fahr for every 1000-ft. increase in altitude. Therefore, if vapor lock does not occur before the airplane leaves the ground and if the fuel temperature follows atmospheric temperature closely, the occurrence of vapor lock while in the air would not be expected under normal conditions. However, the fuel temperature usually remains very much higher than the atmospheric temperature as the airplane climbs. Even after an hour at high altitude, following a rapid climb, the temperature of the fuel in the supply tank is frequently not much lower than it was at the time the airplane left the ground. Furthermore, the temperature of the gasoline in the carbureter float-bowl may rise during the first few thousand feet of climbing. These variations in fuel temperature depend upon the design and installation of the fuel-feed system and upon the conditions of operation of the airplane, in particular, upon the rate of climb.

In very hot weather, the atmospheric temperature up to 10,000 ft. or higher may be considerably above the standard atmospheric values and in fact may not change appreciably over a range of several thousand feet of altitude. Therefore, while the vapor-locking temperature continues to drop at the normal rate, the atmospheric temperature may remain essentially constant. This condition is particularly troublesome in localities where the ground altitude is high.

The entrance of so many variables into the phenomenon of vapor lock in airplanes makes a detailed analysis very difficult in the light of our present information. However, a general analysis of the problem of vapor lock with airplanes indicated that trouble might be anticipated under three different sets of conditions:

(1) In very hot weather, the temperature of the fuel in the line leading to the carbureter may become sufficiently high to interrupt partially the fuel flow after the airplane has landed and stood for a few minutes with the engine idling. While the flow may be sufficient to permit the engine to run smoothly when throttled, engine stoppage probably would occur just after taking off, resulting in a crash.

(2) If the fuel is close to the vapor-locking temperature before the plane leaves the ground, the combined effects of reduction in atmospheric pressure and heating of the fuel in the line leading to the carbureter during a rapid climb might lead to vapor lock at about 2000 to 5000 ft. altitude. Engine stoppage under these conditions would leave some time for maneuvering to a landing field but is hazardous. This type of vapor lock probably is limited to gravity-feed systems.

(3) As an airplane climbs steadily, the atmospheric pressure decreases and, if the fuel in the supply tank does not cool rapidly, an altitude will be reached at which the gasoline will commence to boil. This probably will manifest itself by a loss in power and irregular running of the engine and can ordinarily be cured by descending a few thousand feet. This type of vapor lock essentially limits the ceiling of the airplane and may occur with either gravity or pressure-feed systems.

In cooperation with the Army, the Navy and the National Advisory Committee for Aeronautics, temperatures were measured at various points in the fuel systems of airplanes of five types under a variety of flight conditions. The one outstanding point indicated by these data is that the temperature of the fuel in the feed system tends to drop very slowly as the airplane climbs. Thus a state of vapor lock is approached with increase in altitude. Three types of vapor lock in airplanes are enumerated, and two remedies dealing with fuel-system design are suggested.

General Vapor-Lock Problem

Since even a slight interruption of fuel flow is hazardous while the airplane is in the air, every precaution should be taken to ensure that vapor lock will not occur. Difficulties from vapor lock are attributable either to vapor pressure of the fuel, to the design and installation of the fuel-feed system or to a combination of vapor pressure and fuel-system design. In any specific case it is not easy to decide whether the fuel system or the fuel is at fault. If fuel systems are blamed, it should be recognized that it is possible to produce fuels which will give freedom from vapor lock in present fuel systems under practically all operating conditions. If the fuel is blamed, it should be kept in mind that, while the avoidance of vapor lock imposes restrictions on the upper limit of vapor pressure, the ability to start the engine and to have it warm up easily imposes definite restrictions on the lower limit of vapor pressure.

The difference between the permissible upper and lower limits depends upon the design of the fuel-feed

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[1] Publication approved by the Director of the Bureau of Standards of the Department of Commerce, City of Washington.

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[4] Junior physicist, Bureau of Standards, City of Washington.

system and upon the atmospheric conditions. Under certain conditions it may be extremely difficult to satisfy both requirements, and a compromise may be necessary. In such a case the design of the fuel-feed system employed should be such as to maintain the fuel temperatures as low as possible.

The general problem is one involving both the aviation and the petroleum industries. The ultimate solution lies in the closest cooperation between these two industries. In order to solve the immediate problem, owners of airplanes giving trouble from vapor lock should remodel the fuel systems according to the best practice in well-designed systems, and the petroleum refiner should restrict the vapor pressure of the gasoline and remove all propane. With the airplanes in production at present, most of the responsibility of ensuring freedom from vapor lock lies with the airplane manufacturer, for systems can be installed without any major changes in design which will handle gasolines having vapor pressures at 100 deg. fahr. as high as 10 to 12 lb. per sq. in. without any trouble from vapor lock.

In the study of the vapor-lock problem during the last two years at the Bureau of Standards under the direction of the Cooperative Fuel-Research Steering Committee, various phases of the problem have been investigated. A study of the properties[5] of fuels has shown conclusively that the vapor pressure is an accurate criterion of a general nature for determining the temperature of the fuel at which vapor lock will occur at any altitude. The A. S. T. M. distillation temperature at 10 per cent evaporated is an equally satisfactory criterion for propane-free gasolines. Numerous experiments with fuel-feed systems[6] have led to definite conclusions regarding what constitutes a well-defined fuel-feed system. The present paper paper deals with another phase of the problem; namely, a preliminary study of the fuel temperatures in airplanes during flight. As a background to the consideration of this information, a brief summary will be given of the conclusions reached in the study of the vapor pressures of fuels.

Summary of Vapor-Pressure Work

On the basis of an extensive investigation[5] of the properties of gasolines from the standpoint of vapor lock, it was concluded that the gas-free vapor-pressure[7] was the only essential property of the fuel which determined its vapor-locking tendency, and this was verified by experiments[6] in typical fuel-feed systems. However, the gas-free vapor pressure is very difficult to measure, and it was desirable to have a simple method for the measurement of the vapor-locking tendency. A comparison between Reid vapor-pressures and gas-free vapor pressures indicated that there was a definite relation between the two methods; if the Reid values were multiplied by the factor 1.1, the resulting quantity was equal to the gas-free values, within the experimental error of the Reid method, and this relation was found to be general for all types of gasoline. Hence, using Reid-vapor-pressure values at 100 deg. fahr., the sea-level vapor-locking temperature of a gasoline with a conventional distillation-curve is given by the equation

$$t = 259 - 140 \log p_r \qquad (1)$$

where p_r is the Reid vapor pressure in pounds per square inch and t is the temperature in fahrenheit degrees. The vapor-locking temperature at any altitude is given by a modification of equation (1) as follows:

$$t = 259 - 140 \log \left(\frac{p_r \times 14.7}{p} \right) \qquad (2)$$

where p is the atmospheric pressure at the given altitude, in pounds per square inch. Equations (1) and (2) are represented graphically in Fig. 1, in which the vapor-locking temperatures at various altitudes are plotted against Reid vapor pressures at 100 deg. fahr. It is seen from the figure that a gasoline having a vapor pressure of 10 lb. per sq. in. will vapor-lock at 119 deg. fahr. when the airplane is on the ground at sea level, while at 30,000 ft. the vapor-locking temperature of this same gasoline is 51 deg. fahr.

For gasolines free from propane, it was found that the gas-free vapor pressures could be computed from the temperature at 10 per cent evaporated in the A. S. T. M. distillation test. The relation between vapor-locking temperature t in fahrenheit degrees and the 10-per-cent point $t_{10\%}$ in fahrenheit degrees is as follows:

$$t = \frac{4\ t_{10\%} + 460 \log \left(\frac{p}{14.7} \right)}{4 - \log \left(\frac{p}{14.7} \right)} \qquad (3)$$

where p is the atmospheric pressure in pounds per square inch at the given altitude. This relation is shown graphically for various altitudes in Fig. 2.

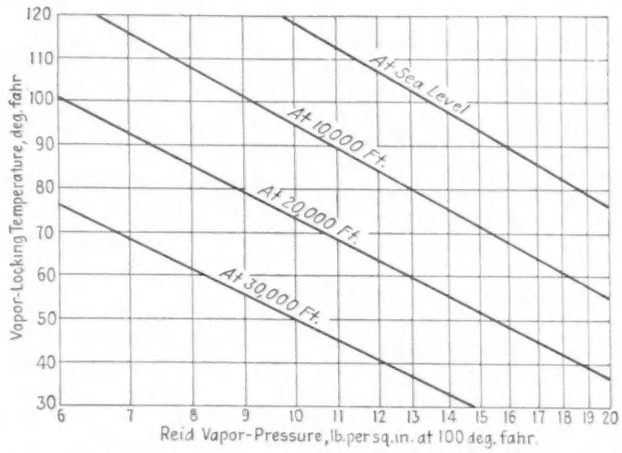

FIG. 1—RELATION BETWEEN VAPOR-LOCKING TEMPERATURE AND REID VAPOR PRESSURE AT VARIOUS ALTITUDES

The equations and the plots give means for predicting with reasonable accuracy the condititons of temperature and altitude under which a fuel of known vapor pressure will give trouble from vapor lock. Therefore, if information is available as to probable fuel temperatures in the fuel-feed system of a given airplane at various altitudes under different conditions of operation, it is possible to estimate the permissible vapor pressure for freedom from vapor lock with that airplane. Some information on fuel-line temperatures in several airplanes during flight is given in the following section of this paper.

Airplane Fuel-Line Temperatures

Flights were made in five airplanes which are described in Table 1. These airplanes are representative of many of the types used by the Army and the Navy.

[5] See S.A.E. JOURNAL, July, 1930, p. 93.

[6] See S.A.E. JOURNAL, August, 1930, p. 217, and October, 1930, p. 443.

[7] See S.A.E. JOURNAL, May, 1929, p. 488.

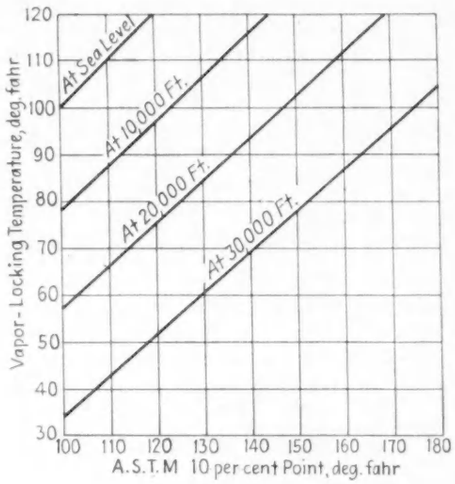

FIG. 2—RELATION BETWEEN A.S.T.M. 10-PER-CENT POINT AND VAPOR-LOCKING TEMPERATURE AT VARIOUS ALTITUDES

Temperature measurements in all cases were made by means of resistance thermometers, since these permitted the use of rugged indicating instruments capable of giving the desired sensitivity under conditions of fairly severe vibration. These resistance thermometers were so constructed that they fitted into specially constructed pipe-fittings inserted in the fuel-feed line. A detailed diagram of the thermometer and fitting and further details regarding their construction are given in a previous paper[8] on automobile fuel-line temperatures. For measurement of fuel temperatures at the carbureter-jet inlet, special fittings were employed to replace the plug under the carbureter jets. The thermometers were interchangeable so that any one could be used in each of the fittings. Temperatures were observed by means of a direct-reading ohmmeter. The precision of the temperature-measuring equipment was 0.5 deg. cent. (1 deg. fahr.).

At recorded intervals of time during each flight, measurements were made of the atmospheric temperature and the altitude was noted. The points at which fuel-temperature data were obtained on the various airplanes are as follows:

Airplane *A:* tank outlet and carbureter bowl
Airplane *B:* tank outlet, fuel-pump outlet and carbureter bowl
Airplane *C:* tank outlet, flowmeter, line near carbureter, and carbureter float-bowl
Airplane *D:* right and left-tank outlets, outlet of three-way valve to center engine, inlets to center and right-engine strainers, and carbureter bowls of center and right engines
Airplane *E:* tank outlet, line between hand-pump and bypass valve, outlet of supercharger relief-valve, inlet to strainer, rear-carbureter inlet, front-carbureter bowl

The flights and temperature measurements on airplanes *D* and *E* were made in cooperation with the Army Air Corps, those on airplanes *A* and *B* in cooperation with the Navy, and those on airplane *C* in cooperation with the National Advisory Committee for Aeronautics. All of the data are presented in graphical form in Figs. 3 to 7, inclusive. In these plots, atmospheric temperature is designated by the symbol +, fuel temperature at the tank outlet by circles and fuel temperature at the carbureter by triangles.

It was considered best to plot the temperature in terms of time after leaving the ground, since such a plot gives more information regarding the conditions prevailing during the flight. As an indication of the altitude attained, an auxiliary scale is shown on each plot. This scale is directly applicable only to the air-temperature curve, which is the lowest one in each case. Referring to Fig. 3, at 15,000 ft. the air temperature is approximately 24 deg. fahr. At this same altitude the temperature of the fuel in the tank is about 68 deg. fahr. Thus, while it is directly applicable only to the air-temperature curve, it can be used indirectly for the other curves as indicated by the example just given. The altitude scales are different, because each depends upon the particular temperature gradient prevailing at the time of the flight. Some of the altitude scales are also irregular, for the same reason.

The temperature data on the observation type of airplane *A* are shown in Fig. 3. As the airplane leaves the ground, the temperature of the gasoline in the tank is the same as that of the atmosphere, while the fuel temperature in the carbureter is about 10 deg. fahr. higher. As the airplane rises, the fuel temperatures in the tank and in the carbureter drop steadily but not as rapidly as the atmospheric temperature. At 15,500 ft., reached in about 30 min. of climbing, the fuel temperature is approximately 50 deg. fahr. above that of the air. As the airplane descends, the fuel temperature rises and returns approximately to its original value as the plane lands. If a gasoline with a vapor pressure of 12 lb. per sq. in. had been used in this trip, the engine

TABLE 1—DESCRIPTION OF AIRPLANES INVESTIGATED

No.	Type	Number of Engines	Fuel System
A	Observation	1	Pressure
B	Training	1	Pressure
C	Bombing	1	Pressure
D	Transport	3	Gravity
E	Pursuit	1	Pressure

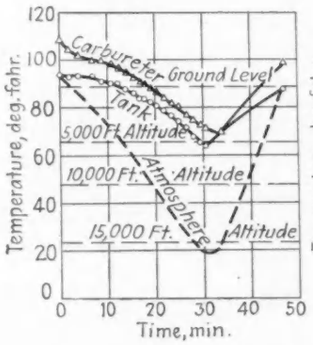

FIG. 3—TEMPERATURE DATA FROM OBSERVATION-TYPE AIRPLANE *A*

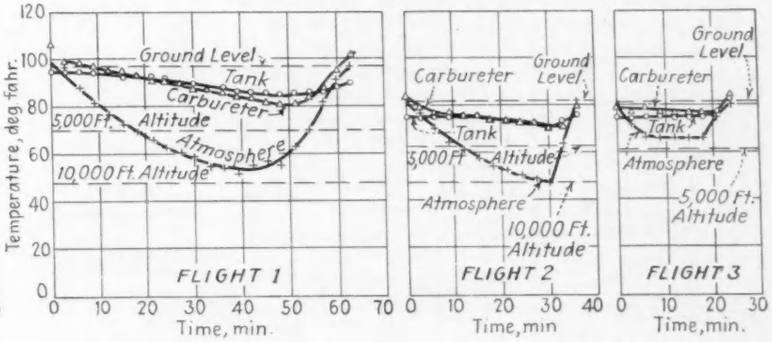

FIG. 4—TEMPERATURE DATA FROM THREE FLIGHTS WITH TRAINING-TYPE AIRPLANE *B*

[8] See S.A.E. JOURNAL, March, 1931, p. 315.

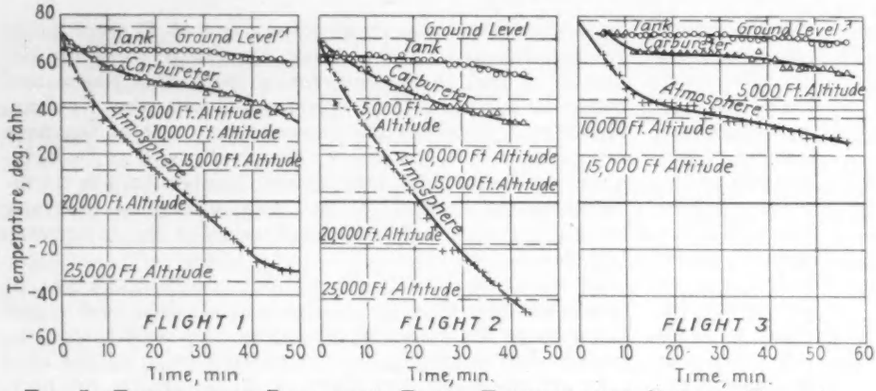

FIG. 5—TEMPERATURE DATA FROM THREE FLIGHTS WITH BOMBING-TYPE AIRPLANE *C*

would have been on the verge of stopping on account of vapor lock throughout the entire climb. From Fig. 1, the vapor-locking temperatures at 0, 5000, 10,000 and 15,000 ft. respectively are 107, 96, 84 and 75 deg. fahr., while the measured fuel-temperatures at the carbureter were 108, 96, 86 and 74 deg. fahr.

Fig. 4 shows the temperature data obtained during three flights with the training type of airplane *B*. As this plane has a low ceiling, it was not feasible to climb above 10,000 ft. The drop in fuel temperature during the climb is not so rapid as with airplane *A*, so this represents a case in which a state of vapor lock is being approached as the airplane rises. If 12-lb.-per-sq.-in. gasoline had been used in flight 1, the fuel would have been about 15 deg. fahr. below the vapor-locking temperature at the ground but would have given trouble from vapor lock at 8000 to 10,000 ft. Flight 3 is interesting in that, during the 10-min. period while the airplane was flying at a constant altitude of 4000 ft., the fuel temperature did not change appreciably.

The curves for the bombing type of airplane *C*, in Fig. 5, show a much smaller change in fuel temperature than with airplane *B*, particularly in view of the low atmospheric-temperatures at the high altitudes that were reached. In this case also the temperature of the fuel in the carbureter is much lower than that in the tank. In flights 1 and 2, the tank temperature changes less than 10 deg. fahr. during 40 to 50 min. of climbing, while the atmosphere temperature decreases about 110 deg. fahr. in the same period. At 25,000 ft. in flight 2, the fuel temperature is actually 90 deg. fahr. above the temperature of the air. Flights 1 and 2 would not have been possible with a gasoline having a vapor pressure higher than 10 lb. per sq. in., because vapor lock would occur at about 25,000 ft. This is a good illustration of the type of flight in which there might be no trouble from vapor lock but in which the ceiling of the airplane would be limited by the vapor pressure of the fuel. The temperature data obtained at the flowmeter and in the line near the carbureter are not shown, as they are not materially different from those in the tank and carbureter.

Fig. 6 shows tank and carbureter temperatures in four flights with a transport type of trimotored airplane *D*. In all cases the temperature of the fuel in the carbureter is considerably higher than of that in the tank. The data on carbureter temperatures at the center engine are the values shown, and it was observed that the carbureters on the outboard engines were somewhat cooler. The fuel temperatures at the outlets from the different tanks did not differ appreciably when fuel was being taken from the tanks. When one tank was shut off, the fuel temperature at the outlet dropped rapidly, but it rose immediately when flow was again started through the line. Rapid climbs were made in flights 1 and 2 to above 15,000 ft., and it was observed that the fuel temperature in the tank did not drop appreciably. Even after 2 hr. of flying at 10,000 ft., as shown in flight 3, the tank temperature had not dropped more than about 10 deg. fahr. below the value at the ground. These flights were made in the winter, and considerably higher differences in temperature between the fuel and the air might be anticipated in hot weather.

The data on the pursuit type of airplane *E*, shown in Fig. 7, are particularly interesting. In this case also values at the tank and carbureter only are shown,

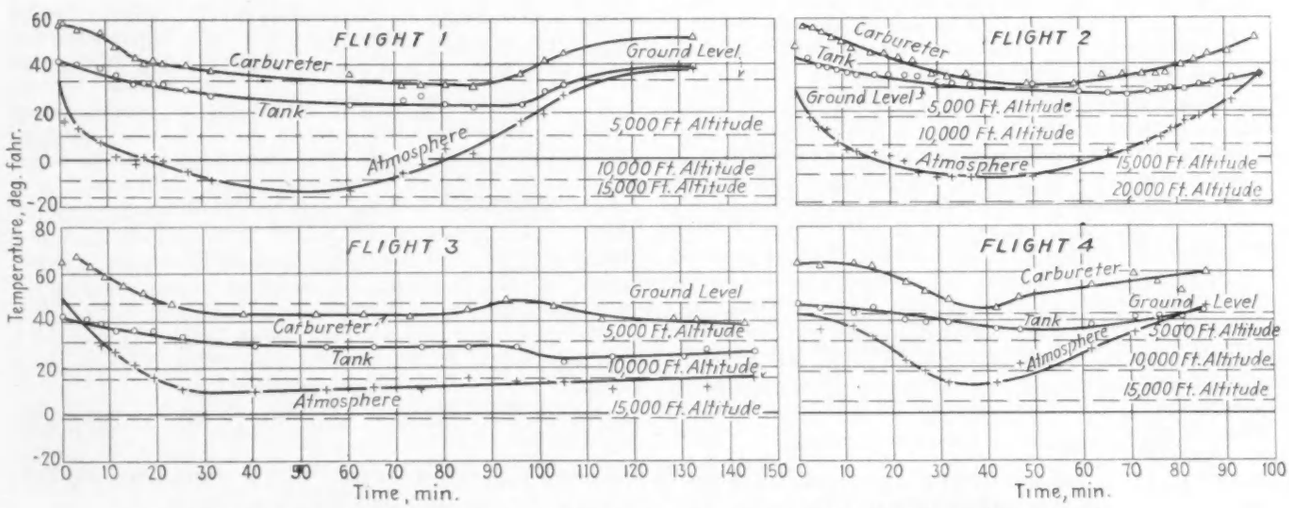

FIG. 6—TEMPERATURE DATA FROM FOUR FLIGHTS WITH TRIMOTORED-TYPE AIRPLANE *D*

as these are representative of the temperatures measured at other points in the fuel system. The fuel temperature was considerably above that of the atmosphere at the time of leaving the ground in all flights, but in every case it followed closely changes in atmospheric temperature, remaining about 90 deg. fahr. above the temperature of the air. This probably is due to heat supplied from the engine. In flight 3, the fuel temperature even increased somewhat as the airplane was maintained at a constant altitude of 25,000 ft. for which are of interest and indicate several things which are suggestive. The one outstanding point which is apparent in connection with these flights is that the temperature of the fuel in the feed system tends to drop very slowly as the airplane climbs. This is very serious in hot weather; for, if a plane stands in the sun for some time before taking off, high fuel-temperatures may be expected, and hence vapor lock is liable to occur before an altitude of many thousands of feet is reached.

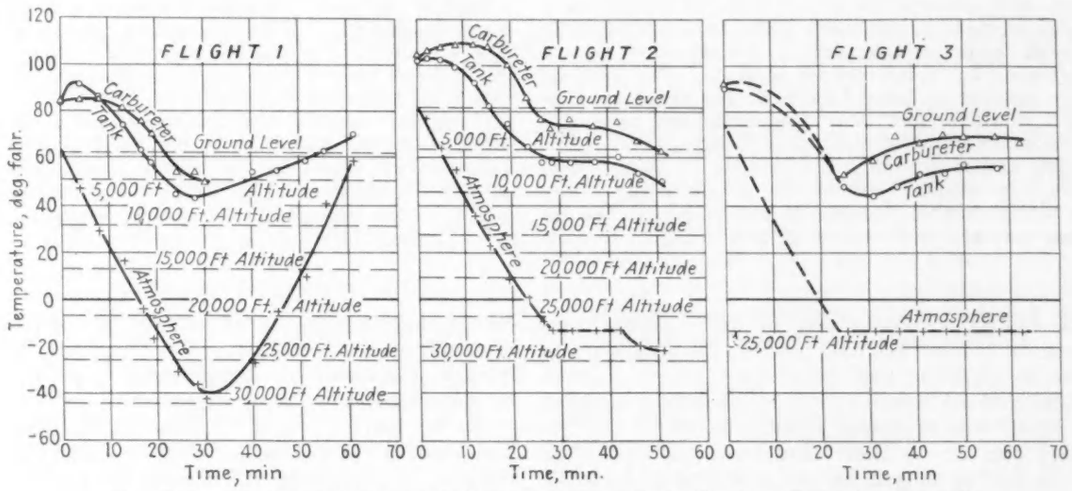

FIG. 7—TEMPERATURE DATA FROM THREE FLIGHTS WITH PURSUIT-TYPE AIRPLANE *E*

about 40 min. In the case of flight 1, the engine was shut off at 28,000 ft. and hence the carbureter temperature readings during the descent are not comparable with those while climbing. Flight 2 is a good illustration of a case in which trouble from vapor lock might be encountered within a few thousand feet of the ground. If a 12-lb.-per-sq.-in. gasoline is taken as an example, there would be no trouble at the ground because the vapor-locking temperature is 119 deg. fahr. and the fuel temperature is 104 deg. fahr. However, at 10,000-ft. altitude the vapor-locking temperature would be 84 deg. fahr. and the recorded fuel-temperature at this altitude was 110 deg. fahr. Therefore vapor lock would have occurred long before the plane reached an altitude of 10,000 ft. A vapor pressure of 7 lb. per sq. in. would be the highest permissible in a gasoline for safe operation on this flight. For flights 1 and 3 the permissible vapor pressures would not be higher than 12 and 8 lb. per sq. in. respectively.

Conclusion

Any general conclusions from the limited amount of data obtained are difficult to make. The airplanes investigated cover in a general way a number of types

The remedy appears to be twofold. Either fuel tanks should be so installed as to ensure good heat interchange with the atmospheric air, or small fuel-radiators placed in the airstream should be employed. The temperature of the fuel in the tank as the airplane leaves the ground and the rate of heat interchange with the atmospheric air are factors which overshadow any minor differences in fuel-system design, although much can be done in the way of improvements in design. If the fuel temperature can be made to change a little more than one-half as fast as the normal atmospheric temperature changes during a climb, then vapor-lock difficulties would be almost entirely eliminated; for, if there is no trouble on the ground, there should be none in the air in normal cases.

Finally, it seems very much worth while for airplane manufacturers to install distant-reading thermometers in the fuel tanks of their airplanes and find on the basis of actual flight tests what temperatures they are likely to encounter under various conditions of flight. Only by such investigative work will the aviation industry be doing its share in cooperating with the petroleum industry to produce satisfactory fuels for safe flights.

Streamlining *Applied to* Automobiles

Metropolitan Section Paper

By Othmar K. Marti[1]

STUDY of aerodynamics was first made in connection with airships and airplanes, asserts the author, and streamlined forms were developed as a result of wind-tunnel tests made by Paul Jaray in Austria and Germany before the World War and supported by mathematical studies. The findings were applied to improvement of the shape of Zeppelin airships, and later the streamline principles were incorporated in automobile designs.

The author presents the results of wind-tunnel tests of streamlined automobile models in this Country which showed reduction by almost one-half in the wind resistance at speeds of 40 and 50 m.p.h., as compared with the conventional American sedan model. Results are also given of road tests of a standard Chrysler car and a Jaray-Chrysler car, using the same chassis model and each seating five passengers. The streamlined car is shown to coast farther, accelerate faster and consume much less fuel than the conventional sedan model.

The paper concludes with a theoretical analysis of the horsepower required to maintain a given car speed, which shows that much less power is needed to drive a streamlined car than a conventional one, and with the enumeration of several other important advantages obtained from streamlining.

THE FIRST serious study of aerodynamics was made in connection with rapidly moving objects, such as dirigible airships and airplanes. Considerable time elapsed before it was realized that suitably shaping these objects would greatly influence the resistance of the air to their movement. Streamlined forms were first developed for aeronautic work as a result of wind-tunnel tests. These tests, supported by mathematical studies, were first conducted by Paul Jaray, who, before the World War, was one of the early designers of airplanes and airships in Austria and Germany. Some of his studies were published in several European periodicals. Unquestionably he laid the foundation for building the first successful streamlined dirigible, together with Count Zeppelin, who placed Mr. Jaray in charge of the aerodynamic work at the Friedrichshafen plant about 1914.

For several years Jaray's entire work along this line was directed toward improvement of the shape of the Zeppelin airships. The influence of his work can clearly be seen in Fig. 1. The LZ-1, at the top, built in 1900, was the original cylindrical bag, having slightly rounded conical ends. The LZ-5 of 1908 and the LZ-18 of 1913, not shown in the drawings, were merely larger examples of the LZ-1, with some slight changes in the steering apparatus and other details.

When Mr. Jaray entered the Zeppelin works, the LZ-40 was under construction; nevertheless, he changed the design so that it approached the streamline form, as is evident in the nose and the tail. In the next ship, the LZ-62, built in 1916, the full effect of Mr. Jaray's influence can be seen in the true streamline, as also used in the LZ-120 and the LZ-126, the Los Angeles type. These last two were the final results of extensive mathematical studies and wind-tunnel experiments on models.

Streamline Principles Applied to Automobiles

When making these studies, Mr. Jaray conceived the idea of applying the same principles to automobiles. However, as the automobile moves close to a stationary surface, new factors had to be taken into consideration; and it may be said that Mr. Jaray has solved this problem and proved, not only in the laboratory by means of models, but also on actual cars, that a streamlined automobile can be designed.

So far, this has been attained by shaping the different parts of the vehicle so as to diminish the resistance to air; for example, the spokes of the wheels. The whole car has been given a low, slender shape, and the body has been shaped somewhat like a torpedo or airship. However, in this way little is accomplished in the diminution of air resistance, for two reasons: First, the whole combination of parts entails such a bad guidance of the streamlines that improvement in the shape of the individual parts cannot produce a perceptible

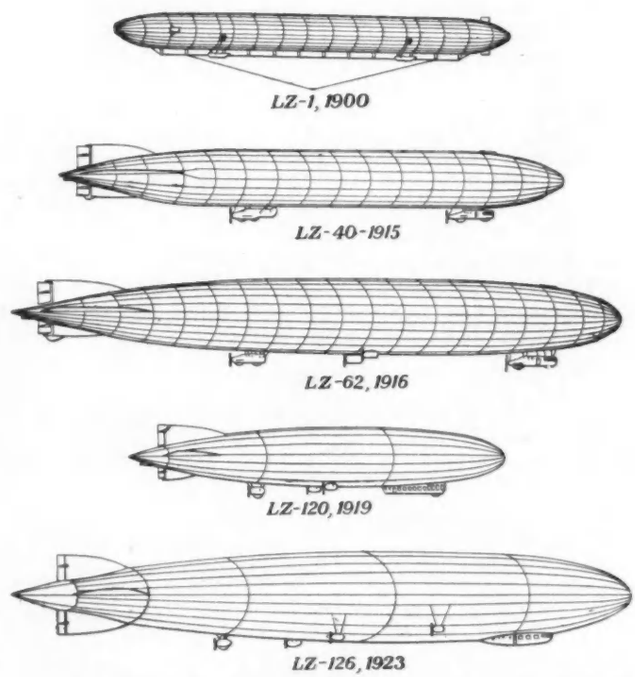

FIG. 1—ZEPPELIN AIRSHIP DESIGNS, SHOWING PROGRESSIVE APPLICATION OF STREAMLINING PRINCIPLES FOLLOWING THE TUBULAR DESIGN OF THE LZ-1 BUILT IN 1900

[1] Chief engineer, American Brown Boveri Co., Camden, N. J.; formerly with Cornell University, Ithaca, N. Y.

effect, the less so as most of the parts concerned are situated in spaces filled with eddies; second, if all the parts are enclosed within a body shaped like an airship, the vision of the driver is impeded and steering becomes difficult.

Automobiles built up to the present usually deflect the air sidewise, transversely to the road. This results in great resistance, large eddies, and, at the rear, a current of air directed obliquely upward, all of which absorb much power. The upward current at the rear produces a partial vacuum which raises the road dust into the eddies following the car. The Jaray car overcomes these drawbacks by enclosing virtually all parts of the car in a shell having the shape of half a streamlined body, the section plane of which is nearly parallel to the road. Such a body deflects the air chiefly upward, as well as rearward, over the top and then down to the bottom, with very little disturbance. The half-streamlined body may carry a top which affords the driver and the passengers unobstructed vision and is shaped to conform to the main portion, especially at the rear.

After extensive studies by Mr. Jaray and laboratory tests conducted by Dr. Wolfgang Klemperer, then in charge of the laboratories at the Zeppelin works in Friedrichshafen and at present in charge of the research laboratories of the Goodyear-Zeppelin Corp., the streamlined automobile shown in Fig. 2 was developed, several cars being equipped with streamlined bodies. Fig. 3 shows, below, a streamlined body built on a standard Chrysler chassis.

The first published mathematical dissertation of the streamline principles as applied to automobiles was written by Mr. Jaray.[2]

Wind-Tunnel Tests of Models

Tests were made in Europe on several types of streamline-shaped automobile models by Mr. Jaray and Dr. Klemperer in the Zeppelin wind-tunnel laboratory. On two models, shown in the lower two drawings of Fig. 3, tests were made in this Country in the Guggenheim Aeronautical Laboratory at New York University under the direction of Prof. Alexander Klemin. In the American tests which were made several years after the German ones and with the refined technique acquired by the aerodynamic laboratories, two of the Friedrichshafen models were rechecked and very satisfactory agreement of results was obtained.

[2] See *Der Motorwagen*, Oct. 20, 1922, p. 551.

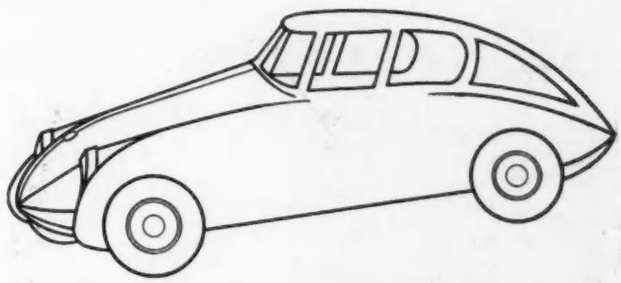

FIG. 2—STREAMLINED AUTOMOBILE DESIGN DEVELOPED FROM STUDIES BY PAUL JARAY AND DR. WOLFGANG KLEMPERER

TABLE 1—WIND-RESISTANCE MEASUREMENTS OF ONE-TENTH-SCALE MODELS IN GUGGENHEIM WIND-TUNNEL AT NEW YORK UNIVERSITY

Model	Resistance Lb.	Resistance Grams
1—Jaray-Chrysler Car	0.633	287
2—Same, but with Streamlined Headlights	0.611	277
3—Same as 2, but with Wheels Flush-Faired Outside	0.589	267
4—Same as 2, but with Wheels Flush-Faired Outside and Inside (computed)	0.578	262
5—Conventional Sedan, Wheels Flush-Faired	1.263	573
6—Same as 5, with Two Spare Wheels	1.299	589

TABLE 2—COMPUTED SAVING IN POWER EFFECTED AT DIFFERENT SPEEDS BY STREAMLINING

Speed, M.P.H.	25	37.5	50	65
Engine Rating, Hp.	Saving in Horsepower, per cent			
8	31	45	53	..
16	25	39	47	..
32	20	32	41	48
64	14	25	34	41

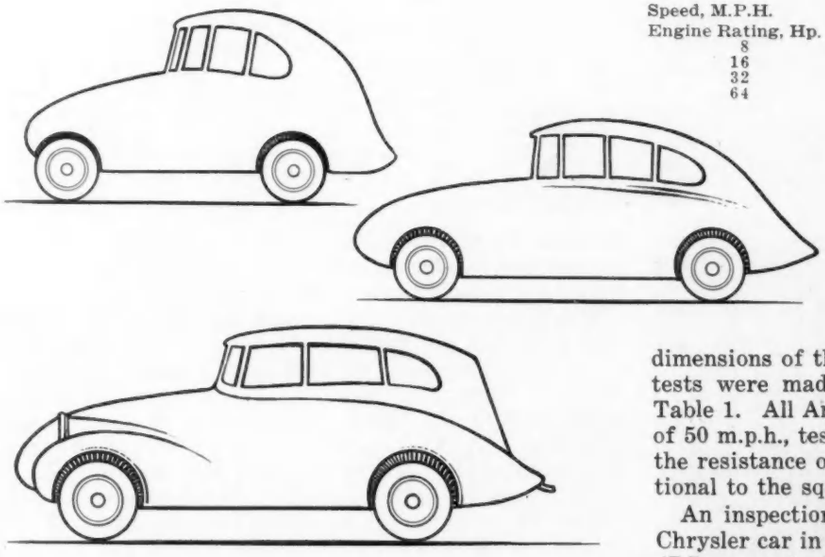

FIG. 3—SUCCESSIVE STREAMLINED BODIES, THE LOWER ONE BUILT ON A STANDARD CHRYSLER CHASSIS

Wind-Tunnel Test Made in America with One-Tenth-Scale Models Showed That This Last Design Had Less than One-Half the Wind Resistance of the Standard Sedan on the Same Chassis

These tests were made using the standard method of suspending the models to be tested from the top of the tunnel by means of two wires and determining the tare resistance of the suspension system by independently fastening the care model to the platform. The scale of the dimensions of the models was about one-tenth size. Six tests were made, which gave the results indicated in Table 1. All American tests were made at a wind speed of 50 m.p.h., test No. 2 being repeated at 40 m.p.h., and the resistance of the car model was found to be proportional to the square of the speed.

An inspection of these results shows that the Jaray-Chrysler car in its original state (1) has a resistance of 47.5 per cent of the resistance of the same chassis with standard sedan body (6). With streamlined headlights and flush-faired wheels (3) this ratio is as low as 43.5 per cent.

Comparative road tests were made with full-size

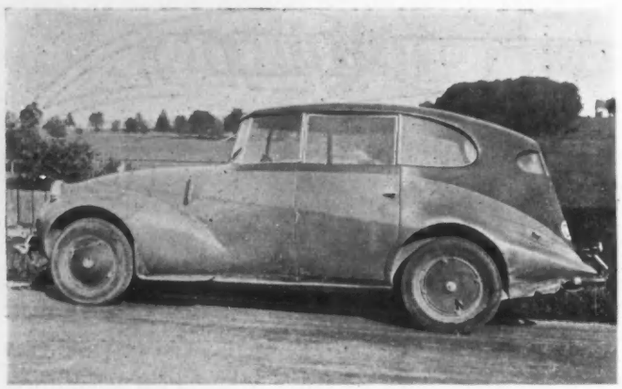

FIG. 4—JARAY-CHRYSLER CAR WITH WHICH ROAD TESTS WERE MADE

Comparative Tests Showed That This Car Coasted 25 to 35 Per Cent Farther, Accelerated about 11 to 17 Per Cent Faster from 6.2 M.P.H. to Final Speeds of 19 to 56 M.P.H., and Consumed about 40 Per Cent Less Fuel at an Average Speed of about 32 M.P.H. than a Standard Five-Passenger Chrysler Sedan

standard Chrysler cars and with Jaray streamlined cars. A photograph of the Chrysler car equipped with streamlined body is shown in Fig. 4. Framing for this body, as built on the chassis, is shown in Fig. 5. The two cars were model 72, with six-cylinder engines of about 72 hp., at 3000 r.p.m., of standard dimensions. The Jaray-Chrysler car will be designated as Car *A*. Its weight, with three passengers, was 4240 lb.; with two passengers, 4030 lb. The standard Chrysler car will be designated as Car *B*. Its weight, with three passengers, was 3900 lb.; with two passengers, 3740 lb. The seating capacity of both cars was five passengers, Car *A* having two doors and car *B* four doors. The tests were made in October, 1928, near Zurich, Switzerland, during fair weather and on a relatively poor macadam road.

Three tests were conducted: First, coasting tests from various initial speeds ranging from 6.2 to 56 m.p.m.; second, acceleration tests from an initial speed of 6.2 m.p.h. to final speeds of 19 to 56 m.p.h.; and, third, fuel-consumption tests on a level stretch of 34.5 miles, with both cars running at the same time.

Coasting Test.—For this test the cars, with two passengers each, were accelerated on a measured course to a point on the road where, at a signal, the clutch was disengaged and the car allowed to coast to a stop, and the coasting distance measured. The results are plotted in Fig. 6, having been corrected for a short slope in the distance coasted and also for weight. At initial speeds between 18 and 56 m.p.h., Car *A* has a coasting distance from 25 to 35 per cent greater than Car *B*, indicating the much smaller air resistance of the car equipped with a streamlined body.

Acceleration Test.—This was so conducted that, by means of a stop-watch, the time was measured which each car required to go from one speed to a higher speed in high gear. Such a test is very difficult to carry out, because of the difficulty of obtaining the same conditions at the moment of acceleration with respect to the engine speed. The results are shown in Fig. 7, corrected as to weight and so on.

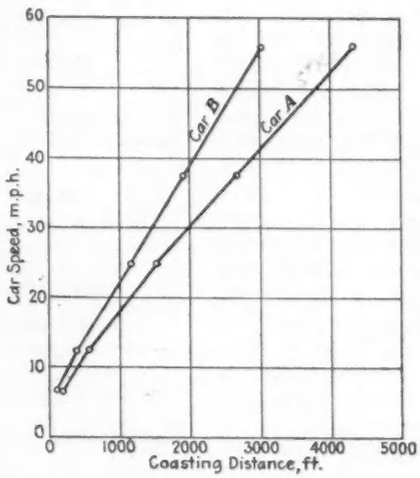

FIG. 6—RESULTS OF COMPARATIVE COASTING TESTS OF JARAY-CHRYSLER CAR, *A*, AND STANDARD CHRYSLER SEDAN, *B*

Both Bodies Were Mounted on Duplicate Standard 72-Hp. Chassis, Had a Seating Capacity of Five Passengers and Car *A* Weighed 290 Lb. More with Two Passengers than Car *B*. The Results Have Been Corrected for the Weight Difference

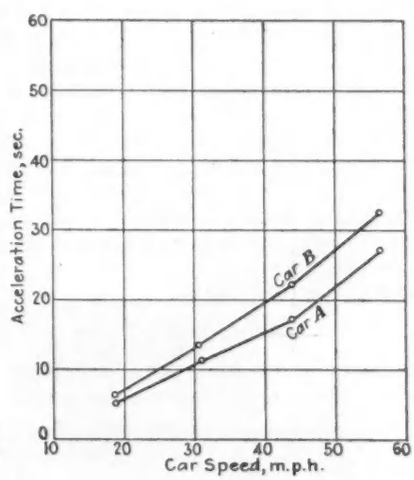

FIG. 7—RESULTS OF COMPARATIVE ACCELERATION TESTS

The Time Was Measured Which Each Car Required To Go in High Gear from an Initial Speed of 6.2 M.P.H. Successively to 19, 31, 44 and 56 M.P.H. The Results Were Corrected for Difference in Weight and Other Factors

Fuel-Consumption Test.—This was made with both cars driven at the same time over the same route and at virtually the same speed. The total distance covered was 34.2 miles. The road was dry and in good condition. Before the start, the gasoline tanks of both cars were filled to capacity, and at the end of the trip they were again filled to capacity, the amounts added being measured with specially calibrated instruments. During the trip the speed varied between 18.7 and 47 m.p.h., the average speed being about 32 m.p.h.

The gasoline consumption of Car *A* was 6.5 liters, (1.72 gal.), and of Car *B*, 10.5 liters (2.77 gal.). The specific gravity of the gasoline was 0.756. The weight of the cars with passengers was: Car *A*, 4250 lb.; Car

(*Concluded on p.* 163)

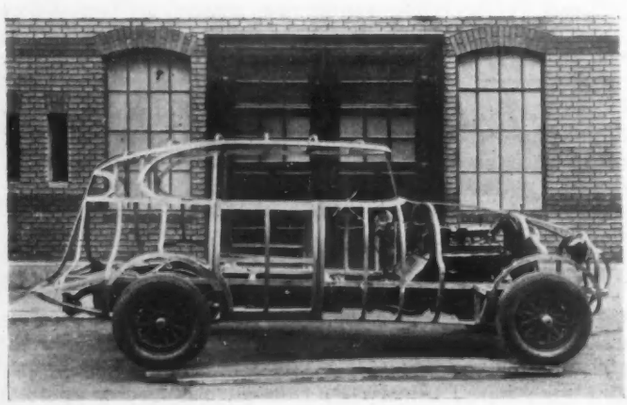

FIG. 5—CHRYSLER CHASSIS WITH FRAMEWORK OF JARAY SCIENTIFICALLY STREAMLINED BODY

Influence of Carbureter Setting and Spark Timing on Knock Ratings

Annual Meeting Paper

By John M. Campbell,[1] Wheeler G. Lovell[2] and T. A. Boyd[3]

THAT the antiknock quality of a motor fuel is best determined by comparison with a standard or reference fuel is generally agreed. The results of the investigation described in this paper show how this comparison may be affected either by the carbureter adjustment or by the spark timing or by both. Therefore, in establishing a standard method of comparing one fuel with another, some definite specification covering each of these two engine-variables must be drawn up. This specification should correspond reasonably well with conventional conditions of engine operation and at the same time with convenient laboratory technique. From the results of this study these conditions would appear to be fulfilled best by using the carbureter setting for maximum knock and the spark timing for maximum power.

THE knock rating of a motor fuel may be defined as the measure of the tendency of the fuel to knock in an engine with respect to that of some standard fuel. A knock rating, therefore, involves a comparison between one fuel and another as it is observed in an engine. This investigation was concerned primarily with the determination of whether two fuels that knock just alike at one carbureter setting or at one spark timing will knock just alike at some other adjustment of the carbureter or of the spark timing. For this purpose several pairs of fuels were selected for comparison.

(1) A commercial gasoline containing benzene and the same gasoline containing lead tetraethyl

(2) A straight-run gasoline and a reference fuel consisting either of benzene in normal heptane or of iso-octane in normal heptane

(3) Two reference fuels, one consisting of benzene in normal heptane and the other of iso-octane in normal heptane.

These fuels were compared by the bouncing-pin indicator, and we assumed that fuels that gave equal bouncing-pin readings during the same period of test were equivalent in tendency to knock.

Description of Experimental Equipment

The experiments were carried out with one of the single-cylinder, variable-compression test-engines being developed in connection with the work of the Subcommittee on Methods of Measuring Detonation of the Co-operative Fuel-Research Steering Committee[4]. The engine was connected to an electric dynamometer for absorbing the output, and the speed was held constant at 600 r.p.m. by a 2-hp. synchronous converter that was connected by V-belts to the flywheel of the engine. An evaporative cooling-system provided with forced circulation maintained the temperature of the jacket water at about 100 deg. cent. (212 deg. fahr.) The engine was fitted with a bouncing-pin indicator for comparing the knock intensity of different fuels.

The carbureter was one that was built at the General Motors Corp. Research Laboratories and has been described before[5]. It had a fixed jet and two float-bowls that were independently adjustable for height so that the mixture ratio for each of the two fuels could be independently controlled as desired by adjusting the height of each float-bowl with respect to the common fuel-jet. A three-way cock inserted in the fuel line between the float-bowls and the jet enabled a change from one fuel to another to be made quickly without interrupting the operation of the engine. The venturi tube of the carbureter was in a horizontal position and discharged the fuel mixture directly into the intake port of the engine. No heat was applied to the mixture before it entered the cylinder-block. The carbureter had no throttle; hence the engine was always operated with the same intake-opening.

The timing of the spark was observed by the flash in a small neon tube that was attached to the crankshaft and that passed a stationary protractor insulated from the ground and connected to the high-tension terminal of the spark-plug. Samples of the exhaust gases were taken at different carbureter-settings during some of the tests, and the carbon-dioxide content was determined to estimate approximately the magnitude of the effect of unit changes in carbureter setting upon the air-fuel ratio.

Benzene in Gasoline Compared with Lead Tetraethyl in Gasoline

Several experiments were made to determine the effect of carbureter setting and of spark timing respectively upon the comparison of a gasoline containing benzene with the same gasoline containing lead tetraethyl. In these experiments a fuel consisting of 40 per cent by volume of benzene in gasoline was compared with fuels containing various concentrations of lead

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[2] Assistant head of fuel section, General Motors Corp. Research Laboratories, Detroit.

[3] M.S.A.E.—Head of fuel section, General Motors Corp. Research Laboratories, Detroit.

[4] See *Bulletin of the American Petroleum Institute*, Jan. 2, 1930, section 3, p. 32.

[5] See S.A.E. JOURNAL, February, 1930, p. 165.

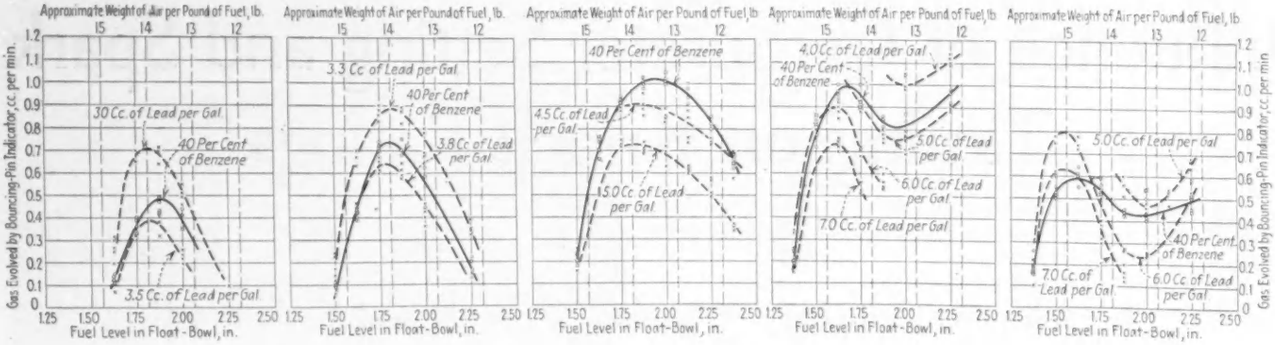
Approximate Weight of Air per Pound of Fuel, lb.
15 14 13 12
Gas Evolved by Bouncing-Pin Indicator, cc. per min.
30 Cc. of Lead per Gal.
40 Per Cent of Benzene
3.5 Cc. of Lead per Gal.
Fuel Level in Float-Bowl, in.
1.25 1.50 1.75 2.00 2.25 2.50
3.3 Cc. of Lead per Gal.
40 Per Cent of Benzene
3.8 Cc. of Lead per Gal.
40 Per Cent of Benzene
4.5 Cc. of Lead per Gal.
5.0 Cc. of Lead per Gal.
4.0 Cc. of Lead per Gal.
40 Per Cent of Benzene
5.0 Cc. of Lead per Gal.
6.0 Cc. of Lead per Gal.
7.0 Cc. of Lead per Gal.
5.0 Cc. of Lead per Gal.
40 Per Cent of Benzene
7.0 Cc. of Lead per Gal.
6.0 Cc. of Lead per Gal.

Fig. 1—Spark Timing 7½ Deg. before Top-Dead-Center; Compression Ratio 6.5 to 1

Fig. 2—Spark Timing 20 Deg. before Top-Dead-Center; Compression Ratio 5.7 to 1

Fig. 3—Spark Timing 28 Deg. before Top-Dead-Center; Compression Ratio 5.65 to 1

Fig. 4—Spark Timing 37½ Deg. before Top-Dead-Center; Compression Ratio 5.7 to 1

Fig. 5—Spark Timing 42 Deg. before Top-Dead-Center; Compression Ratio 5.8 to 1

Effect of Carbureter Setting on Knock Rating

In Making These Tests the Carbureter Setting Which Is Expressed Arbitrarily in Terms of the Fuel Level in the Float-Bowl, Was Varied, While the Spark Timing Remained Fixed. Each Chart Represents a Series of Knock Ratings of 40 Per Cent of Benzene in Gasoline Compared to Various Quantities of Lead Tetraethyl. The Engine Used Was a Single-Cylinder, Variable-Compression Engine Running at a Constant Speed of 600 R.P.M., Having a Jacket-Water Temperature of Approximately 100 Deg. Cent. (212 Deg. Fahr.) and Fitted with a Bouncing-Pin Indicator

tetraethyl in the same gasoline. The object of this comparison was to ascertain the concentration of lead tetraethyl in gasoline which would be equivalent in antiknock effect to 40 per cent of benzene in gasoline at various carbureter-settings and spark timings.

In making this comparison the spark timing was held constant while the carbureter setting was varied. At each carbureter-setting bouncing-pin readings were taken alternately until four readings had been obtained from each fuel. Then the carbureter setting was changed and the bouncing-pin readings continued. After completing a series of bouncing-pin readings taken in this way at different carbureter-settings but at some fixed timing of the spark, the spark timing was changed and the whole process was repeated. In this way five runs were made at spark timings of 7½, 20, 28, 37½ and 42 deg. before top dead-center respectively. The data are presented in Figs. 1 to 5.

In these figures, bouncing-pin readings, expressed as cubic centimeters of gas generated per minute, are plotted on the vertical axis, and carbureter settings, which are expressed arbitrarily in terms of the fuel level in the float-bowls, are plotted along the lower horizontal axis. The approximate mixture-ratios corresponding to different fuel-levels, as determined by referring the percentage of carbon dioxide in the exhaust gases to a representative plot of exhaust-gas composition at different mixture-ratios, are plotted along the upper horizontal axis. These mixture-ratio values apply in a quantitative way only to the gasoline containing lead tetraethyl and not to the mixtures of benzene in gasoline. The composition of the exhaust gases was not appreciably affected by changes in spark timing.

Each of these charts represents a series of knock ratings of 40 per cent of benzene in gasoline with respect to lead tetraethyl in gasoline at different carbureter-setting but at a fixed spark-timing. For example, by interpolation of the data in Fig. 1, at the carbureter settings for maximum knock and at a spark timing of 7½ deg. before top dead-center, 40 per cent of benzene in gasoline would give the same bouncing-pin readings as about 3.4 cc. of lead tetraethyl per gal. in the same gasoline; and, since the bouncing-pin readings would be the same for these two fuels, they are considered to have an equivalent tendency to knock. It will be observed in Fig. 1 that this relative relationship between benzene and lead tetraethyl in gasoline was not seriously affected by changes in carbureter settings corresponding to changes between 13 and 15 lb. of air per lb. of fuel at this spark timing. On the other hand, Fig. 4 shows that at a spark setting of 37½ deg. before top dead-center the same mixture of 40 per cent of benzene in gasoline was equivalent to as much as 6.0 cc. of lead tetraethyl per gal. at a carbureter setting corresponding to about 15 lb. of air per lb. of fuel, but only to about 4.8 cc. of lead tetraethyl per gal. at a carbureter setting corresponding to 13 lb. of air per lb. of fuel.

An analysis of the data in Figs. 1 to 5 shows that, as the timing of the spark is advanced, two important changes take place in the relative knock-ratings of these two types of fuel. First, greater concentrations of lead tetraethyl are necessary to match a given concentration of benzene in the same gasoline; and, second, the magnitude of the influence of carbureter setting upon the relationship between the antiknock effect of lead tetraethyl and of benzene respectively increases.

The specific effect of spark timing, as distinguished from that of the carbureter setting, upon the concentration of lead tetraethyl that would be found equivalent to 40 per cent of benzene is shown in Fig. 6. In this chart the concentration of lead tetraethyl equivalent to 40 per cent of benzene in gasoline, as determined from the data in Figs. 1 to 5 at the carbureter setting for maximum knock, is plotted on the vertical axis and the particular spark-timing at which the determination was made is plotted along the horizontal axis. This chart shows clearly how the concentration of lead tetraethyl that is equivalent to 40 per cent of benzene increases as the spark timing is advanced. Furthermore, from the shape of this curve the inference can be drawn that, at spark timings before that for maximum power, the effect of spark timing on the comparison between fuels containing lead tetraethyl and those containing benzene

is more pronounced than at spark timings after that for maximum power.

In obtaining the data presented in Figs. 1 to 5, the compression ratio, of course, had to be changed when the spark timing was changed, to keep the knock intensity within the range of the bouncing-pin instrument. Consequently, the variations in knock rating that thus far have been ascribed to spark timing conceivably might have been due to the changes in compression ratio that were made at the same time. To preclude this possibility, an experiment was made comparing fuels containing benzene and lead tetraethyl respectively at different spark-timings but at a fixed compression-ratio and at practically constant carbureter-setting, that for maximum knock. This comparison was made by taking bouncing-pin readings at different spark-timings with all other engine-variables remaining constant.

The data for this experiment are plotted in Fig. 7, where bouncing-pin readings for the different fuels are plotted against spark timing. These data show that, even at a fixed compression-ratio and at a substantially constant carbureter-setting, the concentration of lead tetraethyl that is required to match a given concentration of benzene in gasoline depends to a large extent upon the spark timing at which the comparison is made Thus, in this gasoline at a spark-advance of 20 deg., 40 per cent of benzene was equivalent to less than 4.0 cc. of lead tetraethyl per gal., and at a spark-advance of 40 deg. the same concentration of benzene was equivalent in antiknock effect to about 6.0 cc. of lead tetraethyl per gal.

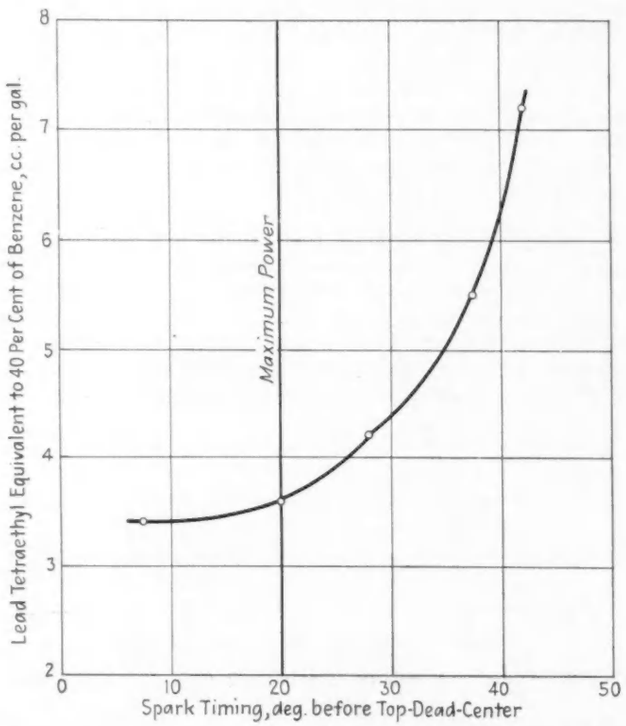

FIG. 6—EFFECT OF SPARK TIMING ON KNOCK RATING

As the Spark Timing Is Advanced, the Concentration of Lead Tetraethyl That Is Equivalent to 40 Per Cent of Benzene Increases. From the Shape of the Curve the Inference Can Be Drawn That the Effect of Spark Timing on the Comparison between Fuels Containing Lead Tetraethyl and Those Containing Benzene Is More Pronounced at Spark Timings before That for Maximum Power Than at Those after

Although the data in Fig. 7 represent different knock-intensities at each spark-timing, no indication is given that this comparison between lead tetraethyl and benzene was affected by changes in knock intensity. These data obtained at different knock-intensities agree with the data in Fig. 6, which represent data obtained at substantially constant knock-intensity. Furthermore, unpublished data that we have obtained in comparing the relationship between the antiknock properties of gasoline solutions of benzene and of lead tetraethyl, as determined by different methods, have shown that this relationship was not affected beyond the experimental error whether the determination was made under conditions of incipient knock or under conditions of fairly severe knock. This was true provided that the only change made to increase the knock intensity was to increase the compression by about one ratio and simultaneously to retard the spark so that it remained at that for maximum power.

A Straight-Run Gasoline Compared with Benzene in Heptane or with Iso-Octane in Heptane

In making further studies of the effect of spark timing on knock ratings, one of the test fuels of the Detonation Subcommittee, designated as gasoline *AAA*-1, was compared with two different reference-fuels. One of the reference fuels consisted of a mixture of normal heptane and iso-octane—2, 2, 4-trimethyl pentane—and the other of a mixture of normal heptane and benzene.

The comparisons were made at two different spark-timings—20 deg. and 40 deg. before top dead-center. All comparisons were made at the carbureter setting for

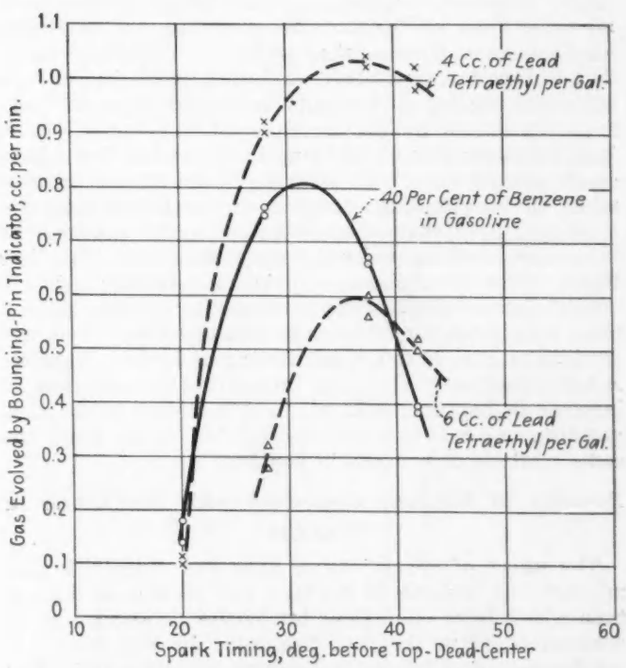

FIG. 7—EFFECT OF SPARK TIMING ON BOUNCING-PIN READINGS

In This Test, Which Was Made with a Compression Ratio of 5.5 to 1 and a Carbureter Setting for Maximum Knock, the Concentration of Lead Tetraethyl That Is Required To Match a Given Concentration of Benzene in Gasoline Was Found To Depend to a Large Extent on the Spark Timing at Which the Comparison Was Made

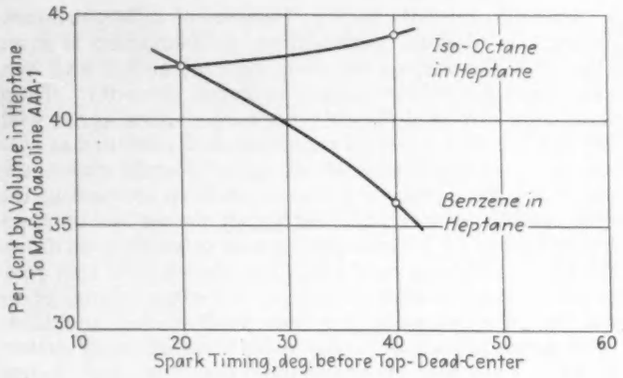

FIG. 8—EFFECT OF SPARK TIMING ON KNOCK RATING

The Results Plotted Were Obtained by Comparing the Knocking Tendency of a Straight-Run Gasoline with Those of Mixtures of Iso-Octane in Heptane and Benzene in Heptane at the Carbureter Setting for Maximum Knock. The Bouncing-Pin Indicator Was Used To Make This Comparison, Which Showed That the Concentrations of Benzene or of Iso-Octane in Heptane Which Were Equivalent to the Straight-Run Gasoline Depend to Some Extent on the Spark Timing at Which the Comparison Was Made

maximum knock. The fuels were matched by the bouncing-pin indicator, and the results are presented in Fig. 8. In this chart the concentrations of benzene or of iso-octane in heptane which were found to be equivalent to gasoline *AAA*-1 depend somewhat upon the timing of the spark at the time the comparison is made.

An explanation for this may be had from a study of Fig. 9. The data plotted in this chart were obtained by comparing gasoline *AAA*-1 with two different mixtures of benzene in heptane at constant compression-ratio. Bouncing-pin readings were taken alternately on all three fuels at the carbureter setting for maximum knock; first at 20 deg., then at 30 deg. and finally at 40 deg. before top dead-center. As the spark timing was advanced the knock intensity increased with all three fuels, as shown by the increase in bouncing-pin readings. But the important thing to observe is that as the spark was advanced the bouncing-pin readings obtained while the engine was running on gasoline *AAA*-1 increased faster than those obtained with mixtures of benzene in heptane under the same conditions. In other words, the rate of increase in knock intensity with respect to spark-advance was greater with gasoline *AAA*-1 than with mixtures of benzene and heptane. Thus, according to Fig. 9, at a spark timing of 23 deg., gasoline *AAA*-1 knocked just like a mixture of 40 per cent of benzene in heptane; and, at a spark timing of 30 deg., gasoline *AAA*-1 knocked appreciably more than the same mixture of benzene in heptane.

Benzene in Heptane Compared with Iso-Octane in Heptane

The effect of spark timing upon the composition of mixtures of benzene in heptane and iso-octane in heptane which have equivalent tendencies to knock can be determined from the data presented in Fig. 8. At a spark-advance of 20 deg., a mixture containing 42.5 per cent by volume of benzene in heptane would be equivalent to 42.5 per cent by volume of iso-octane in heptane since each of these mixtures was equivalent in knocking tendency to gasoline *AAA*-1. On the other hand, if the comparison was made at a spark-advance of 40 deg., only 36 per cent of benzene in heptane would be required to match 44 per cent of iso-octane in heptane since each of these mixtures was equivalent to gasoline *AAA*-1.

The effect of carbureter setting on the comparison between benzene and iso-octane in heptane is shown by the data plotted in Fig. 10. Although these data were obtained from another engine[6], it was similar to the Co-operative Fuel-Research engine and was operated under conditions comparable with those used in obtaining the other data reported in this paper. In Fig. 10 bouncing-pin readings are plotted on the vertical axis against carbureter settings at a fixed spark-timing on the horizontal axis. This chart shows that, at a carbureter setting corresponding to about 13.1 lb. of air per lb. of fuel, based on the exhaust-gas composition of the mixture of iso-octane in heptane, 79 per cent of iso-octane in heptane was equivalent in knocking tendency to 68 per cent of benzene in heptane. But, at a carbureter setting corresponding to about 12.2 lb. of air per lb. of fuel, the same 79 per cent of iso-octane in heptane was equivalent to 68.5 per cent of benzene in heptane. Thus, the knock rating of one reference-fuel with respect to another appears to depend both upon the spark timing and upon the carbureter setting at which the comparison is made.

General Discussion of Results

Methods so far proposed for determining the knocking property of a fuel depend fundamentally upon finding, by experiment in an engine, what mixture of known pure substances knocks like the fuel under investigation. In ordinary work, of course, pure substances are not always used, but gasolines are used which have been compared with the definite pure substances.

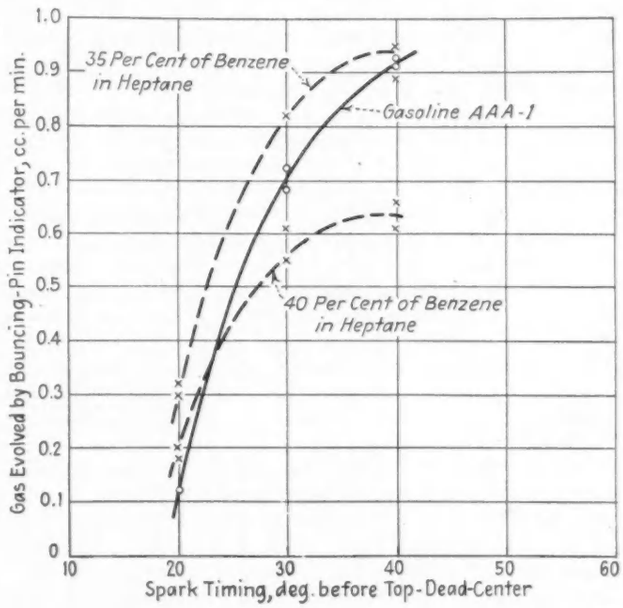

FIG. 9—EFFECT OF SPARK TIMING ON THE BOUNCING-PIN READINGS

In This Test Bouncing-Pin Readings Were Taken Alternately on a Straight-Run Gasoline and Two Different Benzene-Heptane Mixtures at the Carbureter Setting for Maximum Knock and at Spark Timings of 20, 30 and 40 Deg. before Top Dead-Center. The Knock Intensity Increased for All Three Fuels as the Spark Was Advanced, but the Increase for the Straight-Run Gasoline, as Indicated by the Change in the Bouncing-Pin Readings, Was Greater than for the Benzene-Heptane Mixtures under the Same Conditions

[6] See S.A.E. JOURNAL, February, 1930, p. 164.

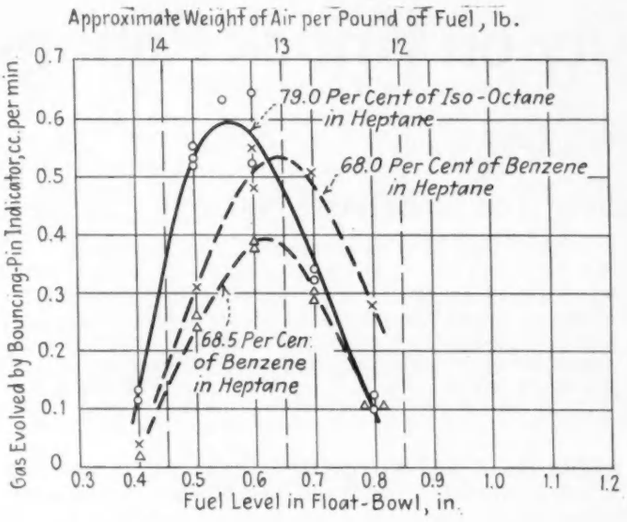

FIG. 10—EFFECT OF CARBURETER SETTING ON THE KNOCK RATING OF BENZENE IN HEPTANE COMPARED TO ISO-OCTANE IN HEPTANE

These Results Were Obtained on a Different Engine from That Used in the Other Tests, Although the Two Were Similar. The Compression Ratio Was 5.8 to 1; the Spark-Advance, 26 Deg.; the Speed, 600 R.P.M., and the Jacket-Water Temperature, 212 Deg. Fahr. Both the Spark Timing and the Carbureter Setting at Which the Comparison Was Made Apparently Affect the Knock Rating of One Reference-Fuel with Respect to Another

The data presented here show that fuels equivalent under one set of conditions may not be equivalent under another set, and in particular when the conditions varied are the spark timing and the mixture ratio. Consequently, in making comparisons that are to be definite and that can be standardized and reproduced, specifying accurately the carbureter setting and spark timing to be used in the making of measurements is necessary.

What carbureter setting and what spark timing are most suitable for a standard method of rating fuels for knock? With respect to carbureter adjustment, the setting for maximum knock is probably the most suitable. The three main reasons why this setting appears to be the best are, first, the adjustment for maximum knock is definite and can be reproduced; second, it is an adjustment that can be made by the same instrumentation as is used for making the knock rating itself; and, third, the carbureter setting for maximum knock is a practical one, because it lies within the range of ordinary engine-operation. The precision with which this adjustment is made is thus suited to any particular method of comparing the antiknock qualities of fuels. Although the mixture ratio for maximum knock is not necessarily the same as that for maximum power, the two adjustments usually are so close together that commercial carbureters designed to compromise between maximum power and maximum fuel-economy will vary enough in their metering to operate at a mixture ratio for maximum knock at some time.

With respect to spark timing the best setting to use apparently is that for maximum power. This setting is not materially affected by ordinary changes in fuel composition at compression ratios below the detonation point. When knock-rating tests are carried out at such a degree of knock intensity that the knock will affect the spark timing for maximum power, it would be preferable not to adjust the spark for maximum power with the knocking fuel but rather to maintain the spark timing for the maximum power that would be obtained under the same engine-conditions but with a fuel that did not knock. If this procedure is followed, determining the spark setting for maximum power independently for every knock-rating is not necessary. Once the spark setting for maximum power has been determined for a particular engine under all the conditions at which it might be used for knock-rating work, future adjustments can be made immediately by referring to the previously determined data.

Making knock ratings at the spark timing for maximum power possesses a number of advantages. First, with such an adjustment the conditions for laboratory measurements will correspond as closely as possible, in respect to spark timing, with those prevailing in actual practice. Second, this adjustment is usually such that the effects of variations in carbureter setting are less than at some of the more advanced spark-timings. Third, the possible effect of small changes in the spark timing appears to be less at the spark timing for maximum power than at more advanced spark-settings. Consequently, we suggest that in making knock measurements, the necessary engine comparisons of the fuels be made at the carbureter setting for maximum knock and at the spark timing for maximum power.

Effect of Sound Intensity on Knock Ratings

Annual Meeting Paper

By Harry F. Huf,[1] J. R. Sabina[2] and J. Bennett Hill[3]

MEASURING knock-sound intensity by a microphone and vacuum-tube amplifying set is described in this paper. Widely varying fuels are compared with mixtures of normal heptane and iso-octane at knock intensities ranging from incipient knock to a knock severe enough to cause preignition. The conclusion is drawn that, for tests on the L-head Cooperative Fuel-Research knock-testing engine, the intensity of knock at which tests are made does not affect the knock ratings if a fuel-matching method is used.

DISCUSSION concerning the effect of knock intensity on the knock rating of a motor fuel has been frequent. The question has been raised whether one of two fuels that cause incipient detonation under identical conditions may not possibly cause destructive detonation before the other. The object of the present work is to develop a means of measuring the knock sound and to determine quantitatively the effect of degree of detonation on knock ratings.

Since the motorist uses sound as a criterion of engine knock, the use of sound measurements in this work rather than some other method such as the bouncing-pin was considered advisable. Therefore a study of the effect of sound intensity had to be preceded by the development of an instrument for measuring the detonation sound, and an electrical device which we call a knock audiometer has been developed. Its essential parts are a microphone, a vacuum-tube amplifying and filtering circuit and a highly damped milliammeter. A diagram of the circuit used in this work is shown in Fig. 1. The microphone, a double-button carbon-granule type, is suspended by coil springs about 2 ft. from the engine cylinder, but is not connected to it in any way. The sounds picked up by the microphone are impressed on the grid of the first vacuum-tube as changes in potential. These changes are amplified about 100 times and conducted through a high-pass filter circuit, which eliminates most of the sounds under a

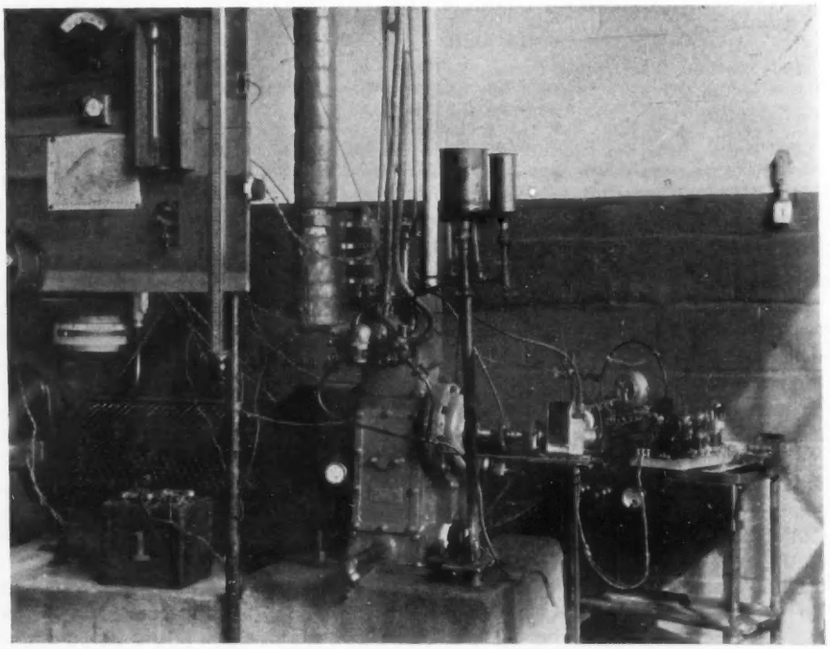

FIG. 2—GENERAL SET-UP OF APPARATUS
The Microphone Is at the Right and the Knock Indicator at the Left, under the Switchboard

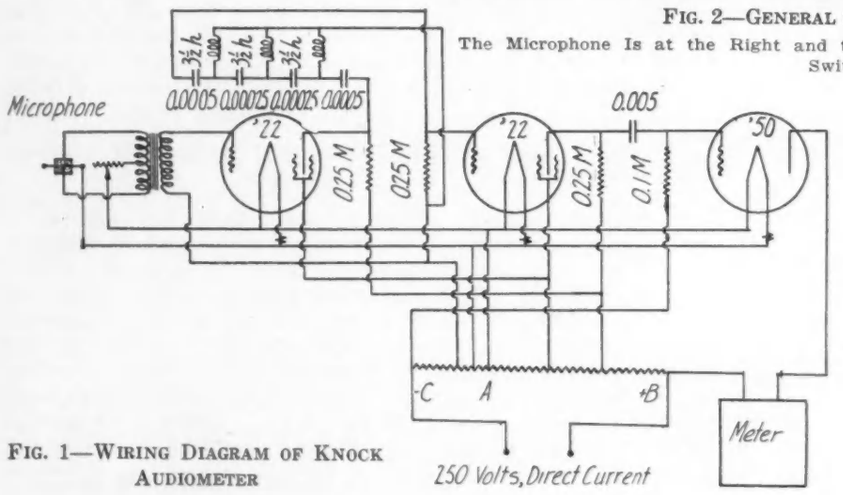

FIG. 1—WIRING DIAGRAM OF KNOCK AUDIOMETER

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[2] Assistant engineer, Atlantic Refining Co., Philadelphia.

[3] M.S.A.E.—Chief chemist, Atlantic Refining Co., Philadelphia.

The authors desire to acknowledge their indebtedness to E. P. Gohn, assistant engineer, Atlantic Refining Co., Philadelphia, who obtained many of the data reported.

frequency of 2000 cycles. An oil-damped milliammeter in the plate circuit of the last tube indicates sound intensity.

The engine used throughout the work was a Cooperative Fuel-Research Steering-Committee knock-testing engine[4]. The general set-up is illustrated by Fig. 2, in which the microphone and amplifier are shown at the right and the detonation meter at the left, just under the switch-board.

The apparatus as described has been satisfactory for the purpose of this investigation, but our experience with it has indicated the possibility of certain improvements. For example, the adaptability of microphones of carbon, condenser and induction types is being studied; and it seems advisable to enclose the microphone in a chamber attached to the engine so as to better eliminate outside noises above the range of the filter.

Procedure in Making Tests

Using the audiometer and opening the throttle gradually, the indicator is found to change very little until detonation begins. A nondetonating fuel will give virtually no change as the throttle is opened, as will be seen from the "blank" curve in Fig. 4. Detonation is indicated by a rise in the indicator reading before the ear becomes sensible of it, and the meter registers about 64 at the point of so-called incipient detonation. The knock sound increases rapidly from this point with throttle opening. Preignition generally sets in at a scale reading of about 110. The meter range of knock such as is commonly indicated by the bouncing-pin is from 80 to 105. In making the test, the mixture ratio was adjusted to maximum knock before each reading. A constant speed of 750 r.p.m. was maintained. The throttle opening was recorded indirectly by measuring intake-manifold pressure. Data are shown graphically in the form of curves in which knock-audiometer readings are plotted against intake-manometer readings.

Three sets of curves are presented as Figs. 3, 4 and 5, showing respectively a group of blends of iso-octane and normal heptane, a group of benzol blends with a base gasoline, and a group of tetraethyl-lead blends with the same base gasoline. The groups of curves show a tendency to fan out or diverge as the knocking becomes more severe. Figs. 6 and 7, showing respectively comparisons of two benzol and two tetraethyl-lead blends with iso-octane-heptane mixtures, indicate that when these materials are tested under comparable conditions the curves of two fuels that are nearly alike in antiknock quality are parallel.

A comparison of various knock-inhibiting materials is shown in Figs. 8 and 9. The base fuel in each case is the same as that used for the benzol and tetraethyl-lead groups. Anilin, ethyl alcohol, iron carbonyl and xylidene cause no deviation from parallelism to iso-octane-heptane curves. Included in Fig. 9 is a curve from a cracked gasoline made by the Cross process, which also is parallel to an iso-octane curve. Gasolines from several crude sources are compared with iso-octane-heptane mixtures in Figs. 10 and 11 and their curves are shown to be parallel. A number of tests on the California fuel and numerous tests of the 55-per-cent-octane blend indicate the reproducibility of the test.

An interesting point is that the predominant frequency of the detonation sound from the L-head Cooperative Fuel-Research engine, when matched with an oscillator, was placed between 2800 and 3100 cycles per sec.

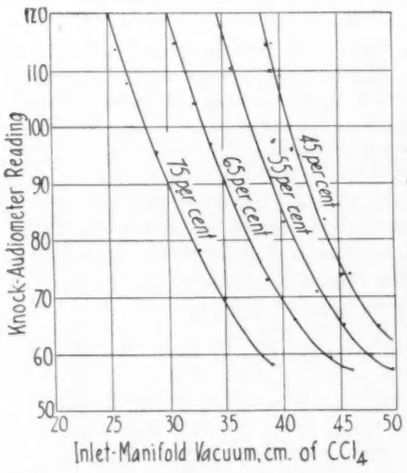

FIG. 3—CURVES OF ISO-OCTANE-HEPTANE GROUP

The Percentage of Iso-Octane Is Indicated on Each Curve, the Remainder of the Mixture Being Heptane. The Two Sets of Points on the 45-Per-Cent Curve Indicate the Reproducibility of the Tests

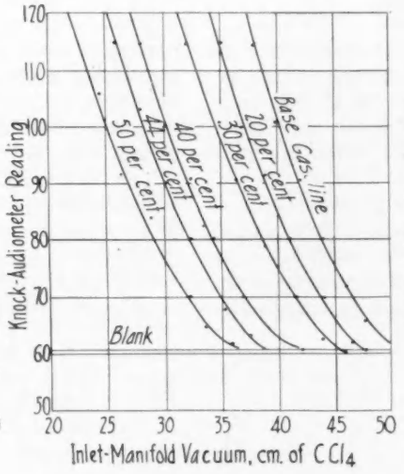

FIG. 4—CURVES OF BENZOL GROUP

Base Gasoline Was Used for the Curve at the Right and Benzol Alone for the Horizontal "Blank" Curve. The Percentage of Benzol Is Indicated on the Other Curves

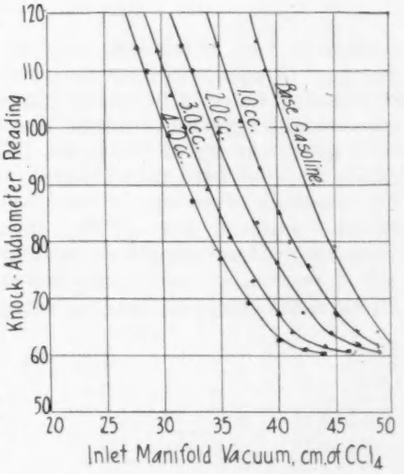

FIG. 5—CURVES OF TETRAETHYL-LEAD GROUP

Base Gasoline Was Used for the Curve at the Right. The Quantity of Tetraethyl-Lead per Gallon of Base Gasoline Is Indicated on the Other Curves

Conclusions

The data collected indicate that the degree of detonation at which a comparison of fuels is made does not appreciably affect the knock ratings of these fuels in the Cooperative Fuel-Research knock-testing engine,

[4] See *Bulletin of the American Petroleum Institute*, Jan. 2, 1930, section 3, p. 32.

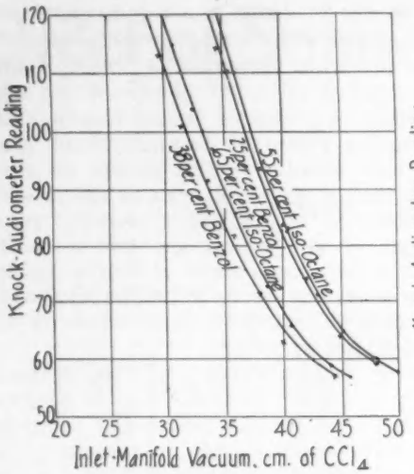

FIG. 6—CURVES OF BENZOL BLENDS PLOTTED WITH ISO-OCTANE-HEPTANE BLENDS

Percentages of the Blends Are Indicated as in Figs. 3 and 4

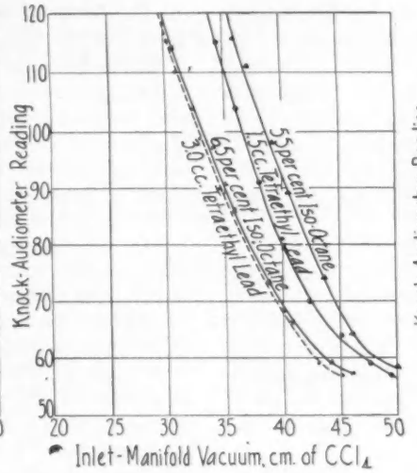

FIG. 7—CURVES OF TETRAETHYL-LEAD MIXTURES PLOTTED WITH ISO-OCTANE-HEPTANE BLENDS

Mixtures Are Indicated as in Figs. 3 and 5

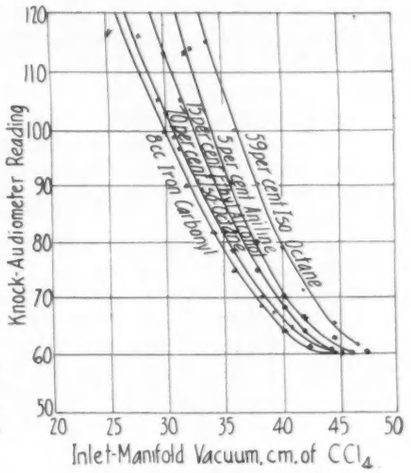

FIG. 8—CURVES OF KNOCK INHIBITORS PLOTTED WITH ISO-OCTANE-HEPTANE BLENDS

The Inhibitors Indicated on the Various Curves Were Used with the Same Base Gasoline That Was Used in the Other Tests

provided the fuel is matched with a sub-standard reference fuel of approximately the same knock rating as the sample. It should be borne in mind that this conclusion should apply only to the one engine, and that, while a great variety of fuels have been tested, all possibilities may not have been covered.

The tendency of groups of curves to diverge at loud knocking—those in Fig. 3, for example—may cause inconsistency if a sample is compared with a sub-standard reference fuel considerably different from it in knock value. For example, an attempt to rate a 75-per-cent octane fuel by measuring intake-manifold depression and using a 55-per-cent-octane substandard reference fuel would result in inconsistent results unless approximately uniform knock intensity is used from day to day. Matching fuels eliminates this difficulty.

The determination of knock ratings by measuring sound with the audiometer has been found very satisfactory as a routine test when used with a dual-float carbureter. The electrical measurement of sound eliminates part of the human element, particularly that occasioned by ear fatigue of the operator.

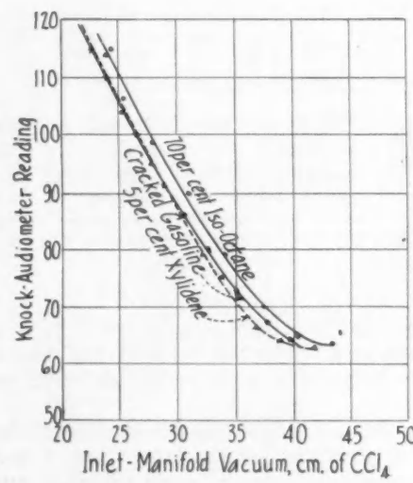

FIG. 9—CURVES OF XYLIDENE AND CRACKED GASOLINE WITH ISO-OCTANE-HEPTANE BLENDS

The Xylidene Mixture Is with Base Gasoline

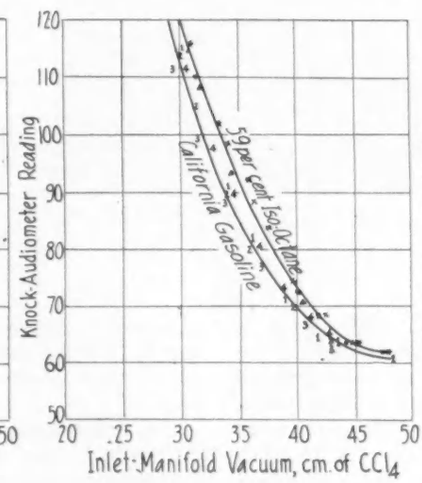

FIG. 10—CURVES OF CALIFORNIA GASOLINES PLOTTED WITH ISO-OCTANE-HEPTANE BLENDS

Numbers Represent the Tests on California Gasoline and Other Symbols Represent Tests on the Blend

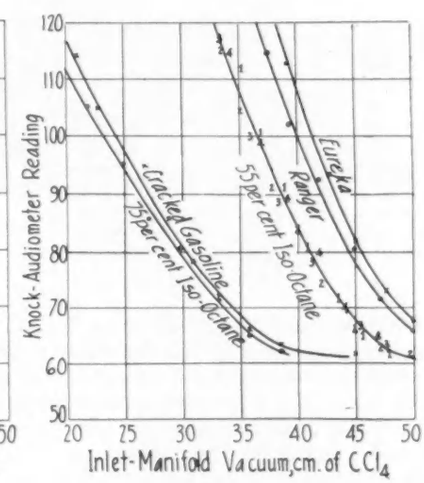

FIG. 11 — CURVES OF COMMERCIAL GASOLINES COMPARED WITH TWO BLENDS

The Two Commercial Gasolines Are Obtained from Different Crude Oils

Bouncing-Pin versus Throttle-Audibility

Annual Meeting Paper

By Neil MacCoull[1]

EXPERIMENTS to determine if any difference in fuel matching by bouncing-pin or throttle-audibility on the same engine are described, also tests to determine if the Cooperative-Fuel-Research and Series-30 Ethyl Gasoline Corp. engines gave similar results for either method. To check these tests another study to find the relative precision of these two methods of knock testing was made. From these tests the conclusion is drawn that, with few exceptions, little difference could be detected in matching fuels on either the Ethyl Gasoline Corp. Series-30 or the Cooperative Fuel-Research engine.

NOW that rating knock values in terms of a blend of iso-octane and normal heptane has become standard, all knock measurements have become essentially methods of matching some fuel, either directly or indirectly, against a blend of these two chemicals. The object of the work described here was to determine if any difference in matching by bouncing-pin or throttle-audibility on the same engine could be detected.

The first experiments were carried out on the Series-30 Ethyl Gasoline Corp. engine and consisted in determining, by cut-and-try methods, the percentage of benzol[2] that must be added to a commercial motor gasoline to equal the antiknock values of 1, 2, 3 and 4 cc. of tetraethyl lead per gallon of the same gasoline. The so-called matching method, which is standard procedure for the Ethyl Gasoline Corp. engine, was used. Readings were taken with the usual bouncing-pin and knockmeter. The data secured are given in Table 1 for the bouncing-pin and throttle-audibility method on the same engine. Slight mechanical changes had to be made so that the audibility reading could be taken on this engine. A micrometer adjustment was provided for the throttle, and the same manometer was used for observing the intake vacuum as is standard for other Cooperative Fuel-Research engines. The agreement between these two methods is very satisfactory, the average difference being only ½ per cent of benzol.

Another study was made to find the relative precision of these two methods of knock testing. In this work several test samples containing various quantities of lead in a given reference-gasoline were repeatedly supplied to routine operators, who were not informed of the lead content. They were instructed to match the samples against a series made up of the same reference-gasoline, with known quantities of lead in steps advancing by increments of 0.2 cc. of lead. Table 2 shows the results obtained with the bouncing-pin and the throttle-audibility methods. The average of all readings on each group of samples and the mean variation from that average are given for each method. The bouncing-pin method was used on the Series-30 Ethyl Gasoline Corp. engine, and the tests by the throttle-audibility method were carried out on the L-head Cooperative Fuel-Research engine, since previous data indicated that these two engines give practically the same results. The skill of the operator was cancelled in most cases by having each operator take the readings on both engines. The results obtained show that no appreciable advantage exists for one method over the other in regard to accuracy.

TABLE 1—BENZOL EQUIVALENTS BY BOUNCING-PIN AND THROTTLE-AUDIBILITY METHODS ON THE SERIES-30 ETHYL GASOLINE CORP. ENGINE

Tetraethyl-Lead Content, Cc. per Gal.	Benzol Equivalent, Per Cent	
	Bouncing-Pin	Throttle-Audibility
1	13	16
2	30	31
3	38	38
4	44	46

TABLE 2—RESULTS OBTAINED IN ROUTINE TESTING

Lead Actually Added, cc. per gal.	1.5	1.8	2.0
Throttle-Audibility Method and Cooperative Fuel-Research Engine			
Lead Found, cc. per gal.			
Engine Operator			
A[a]	1.4	1.6	1.9
B[a]	1.4	1.7	2.0
B[a]	1.6	1.7	1.8
A[a]	1.4	1.7	1.9
B	1.5	1.8	2.1
C	1.4	1.8	1.8
B	1.6	1.8	2.0
C	1.5	1.8	2.0
B	1.5	2.0	2.1
B	1.6	1.9	2.1
Average Lead Found, cc. per gal.	1.49	1.78	1.97
Mean Variation, cc. per gal.[b]	0.07	0.08	0.096
Bouncing-Pin Method and Ethyl Gasoline Corp. Engine			
Engine Operator			
A	1.7	1.8	2.0
B	1.5	1.6	2.2
B	1.4	1.8	1.8
A	1.6	1.8	2.0
C	1.5	1.8	2.0
B	1.5	1.8	2.0
B	1.5	1.8	2.0
B	1.5	2.0	1.8
B	1.8	1.8	2.0
B	1.5	1.8	2.0
Average Lead Found, cc. per gal.	1.55	1.80	1.98
Mean Variation, cc. per gal.[c]	0.09	0.04	0.07

[a] These four readings were taken with a single-float carbureter. Matching was thus indirect and had to be done by readings of manifold vacuum.

[b] Average mean variation for throttle-audibility method was 0.08 cc. per gal.

[c] Average mean variation for bouncing-pin method was 0.07 cc. per gal.

[1] M.S.A.E.—Automotive engineer, Texas Co., New York City.

[2] A grade known to the trade as purified.

Table 3 shows corresponding data for 30 and 32 per cent of benzol blended in the same reference-gasoline. These samples were included for the double purpose of checking the finding of Table 1, which showed that the benzol equivalent of lead is not appreciably affected by the method used, and also to see if the accuracy of matching benzol blends by audibility is as good as when using lead only. This latter step was taken because the sound of a benzol knock is noticeably different from that of lead knock.

In regard to the precision of these two methods, the results show that but little reason for choice exists. The fact that the bouncing-pin method showed that slightly more lead was required to match a given percentage of benzol in Table 3, or slightly less benzol was needed to match a given percentage of lead in Table 1, may be due to the fact that the proportion of spent exhaust-gases mixed with the combustible charge was less.

While we seem safe in drawing the conclusion that but little difference in matching fuels by either the bouncing-pin or throttle-audibility method can be detected, we have secured a few contradictory results. These we cannot as yet explain except with the belief that, in the light of the data presented, they must have been in error. These discrepancies are, of course, being investigated.

These findings are nicely substantiated by the paper presented by Huf, Sabina and Hill[3]. Since they conclude that the intensity of knock does not appreciably influence knock ratings by matching, the light knock obtained with the throttle-audibility method naturally is expected to give similar results to those obtained with the heavy knock required by the bouncing-pin method.

[3] See p. 134.

TABLE 3—RESULTS OF MATCHING BENZOL BLENDS AGAINST TETRAETHYL LEAD

Benzol in Reference Gasoline, per cent	30	32
Throttle-Audibility Method and Cooperative Fuel-Research Engine		
Engine Operator	Lead-Equivalent, cc. per gal.	
B	1.7	1.8
A	1.9	2.0
C	1.8	2.0
C	1.7	2.0
C	1.9	2.1
B	1.8	2.2
B	2.0	2.1
B	1.8	2.0
B	1.9	2.1
B	2.0	2.2
Average Lead-Equivalent, cc. per gal.	1.85	2.05
Mean Variation, cc. per gal.	0.09	0.09
Bouncing-Pin Method and Ethyl Gasoline Corp. Engine		
Engine Operator		
B	2.0	2.2
A	2.2	2.0
A	2.0	2.3
C	2.3	2.0
C	2.0	2.2
B	1.9	2.1
B	1.9	2.2
B	2.0	2.2
B	2.2	2.2
B	2.2	2.0
Average Lead-Equivalent, cc. per gal.	2.07	2.14
Mean Variation, cc. per gal.	0.12	0.09

Evidence thus indicates that the throttle-audibility method and the bouncing-pin method give substantially the same results in matching fuels on either the Series-30 Ethyl Gasoline Corp. or the Cooperative Fuel-Research engine.

The Engineering Department as an Army

THE AUTOMOTIVE industry of today has a place in its ranks for scientists and technicians in the fields of acoustics, electricity, chemistry, metallurgy and even radio, which is the most recent addition to our line of effort.

I like to think of an engineering department as an army going into battle. Scouting and reconnoitering parties are going on ahead. These are our research men looking far ahead and delving into many new ideas in the search for something new and radical that may be better than the present ones. The rank and file of the army are consolidating positions. These represent the regular departments working on routine bread-and-butter ideas, which are safe and ready for present use. Back of the line of action are the officers, whose experience cautions against going forward too rapidly. They lean toward conservatism, thoroughly trying out an idea before adopting it.

The business depression of the last year and a half has given an added impetus to all engineering work. With production and sales down, engineering has been called upon to put forward unusual effort toward perfecting products. Subsequent constructions will demonstrate that the depression will not prove to have been an unmixed evil, when consideration is given to the numerous improvements that will have resulted therefrom.—From an address before the Canadian Section by H. T. Woolson, chief engineer of the Chrysler Corp.

Time Lag in Detonation Determinations

Annual Meeting Paper

By Neil MacCoull[1]

IN matching one fuel against another directly with a double-float carbureter, the knock sometimes either disappears or increases in intensity when the change from one fuel to the other is made. Results of a study of this subject, which was made recently, are presented in the paper.

From the tests the conclusion is drawn that means should be provided to dry out the mixture between the carbureter and the cylinder-block of the engine used for antiknock measurement. Before a satisfactory answer to the problem can be reached, however, several other points require further investigation.

IN making antiknock determinations by matching one gasoline against another directly, with a double-float carbureter, sometimes the knock has been observed to disappear the instant the carbureter is switched from one fuel to the other even though the two fuels may be of equal knock-value. Sometimes the knock increases in intensity when the switchover is made. This phenomenon, which is called time lag, is especially noticeable when matching fuels differing widely in composition, such as a benzol blend and a gasoline containing tetraethyl lead. A study of this subject has been made with the Midgley bouncing-pin and knock-meter as used by the Ethyl Gasoline Corp. Fig. 1 shows knock-meter readings taken while running at 10-sec. intervals before and after a change-over from a Pennsylvania gasoline containing 3 cc. of tetraethyl lead per gal. to a blend of 36 per cent of benzol with the same gasoline. The variation of the individual readings from smooth lines indicates a characteristic of the bouncing-pin readings. Since the mean value of the knock-meter readings finally reached the same value after the change-over that it had before, the two fuels are considered to be of equal antiknock value. The curve at the top of Fig. 2 shows a similar record for a change-over from a California aviation gasoline to an equivalent blend of benzol with a good motor gasoline, and a change back to the California aviation gasoline. The lower curve shows similar data for the same aviation gasoline and for motor gasoline raised to equal antiknock value with lead instead of benzol. The point of principal interest in such curves is that from 200 to 400 sec. may be required after the change-over before the knock resumes its normal value. Therefore, readings taken in less than 7 min. might be considerably in error. Even greater time-lag is sometimes observed, but none has been noticed when changing from one leaded fuel to another.

The desirability of reducing time lag is clearly evident, not only for minimizing the possibility of errors which might develop if insufficient time is given before readings are taken, but also to be able to speed up the process of taking readings. To reduce time lag, something must be known about its cause. The first hypothesis suggested was that the piston temperature might be different when running on different fuels and that the time lag might be the time required for its temperature to come to equilibrium. Accordingly, a thermocouple was installed in the center of the piston-head, and connections made to a pair of prongs that contacted at the bottom of the stroke with connections leading to a potentiometer[2]. The results, shown at the bottom of Fig. 1, indicated that the piston temperature was not only the same for all fuels, but that the piston temperature followed the same curve as the knock-meter. When a fuel change-over was made and the knock faded out, the piston temperature dropped also, returning to the normal temperature at the same rate as did the readings of the knock-meter.

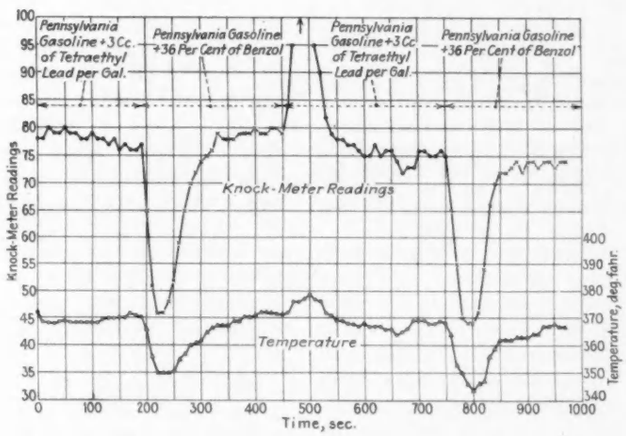
Pennsylvania Gasoline +3 Cc. of Tetraethyl Lead per Gal.
Pennsylvania Gasoline +36 Per Cent of Benzol
Pennsylvania Gasoline +3 Cc of Tetraethyl Lead per Gal.
Pennsylvania Gasoline +36 Per Cent of Benzol
Knock-Meter Readings
Temperature
Knock-Meter Readings
Temperature, deg fahr
Time, sec.

FIG. 1—CURVE OF KNOCK-METER READINGS SHOWING THE EFFECT OF CHANGING FROM ONE FUEL TO ANOTHER

These Readings Were Taken at 10-Sec. Intervals Before and After the Fuel Was Changed from a Gasoline Containing 1 Cc. of Tetraethyl Lead per Gal. to a Blend of 19 Per Cent of Benzol in the Same Gasoline

The next point of attack was the intake system between the carbureter and cylinder. Any unevenness in the supply of unvaporized fuel would naturally have some effect, because the distribution of various antiknock agents, as the gasolines containing them are evaporated, may be very different. For instance, samples of a gasoline containing 3 cc. of lead in one case and 49 per cent of benzol in another were cut into five equal fractions by distilling with steam, with the results given in Table 1.

Thus the heavy ends of a leaded gasoline are seen to have a far greater anti-

[1] M.S.A.E. — Automotive engineer, Texas Co., New York City.

[2] See Air Corps Technical Report No. 2825 on Method of Measuring Temperature of Pistons.

knock value than heavy ends of a benzol blend. Conversely, the light ends of a benzol blend are superior to those from a leaded gasoline. In an engine using a wet mixture, considerable difference may be noticed in the behavior of two gasolines that would show equal antiknock value in a dry mixture. This would be particularly evident when anything changes a steady rate of fuel flow, such as switching from one fuel to another with a double-float carbureter, or when accelerating an engine. Conceivably this might be the cause of great peculiarities in matching fuels on multi-cylinder cars on the road, if their fuel mixtures are wet.

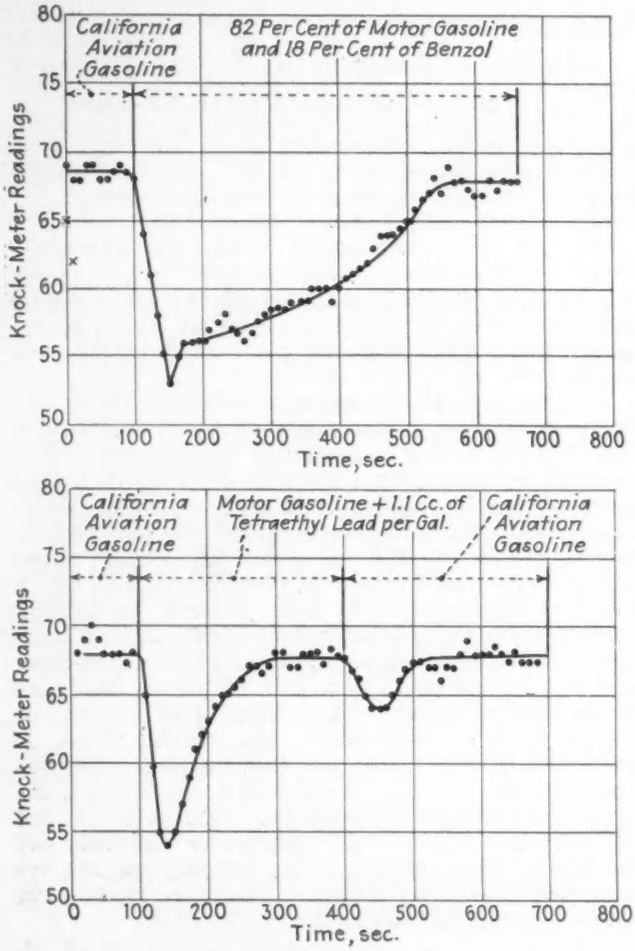
California Aviation Gasoline
82 Per Cent of Motor Gasoline and 18 Per Cent of Benzol
Knock-Meter Readings
Time, sec.
California Aviation Gasoline
Motor Gasoline + 1.1 Cc. of Tetraethyl Lead per Gal.
California Aviation Gasoline
Knock-Meter Readings
Time, sec.

FIG. 2—KNOCK-METER READINGS SHOWING THE EFFECT OF CHANGING FROM A STRAIGHT TO A BLENDED FUEL AND BACK AGAIN

The Upper Curve Is for a California Aviation Gasoline and an Equivalent Blend of Benzol with a Good Motor Gasoline. In the Lower Curve the Same Aviation and Motor Gasolines Were Used, but the Antiknock Agent Used Was Tetraethyl Lead Instead of Benzol. The Principal Point of Interest about These Curves Is That the Knock May Not Resume Its Normal Value Until between 200 and 400 Sec. After the Change-Over Is Made

TABLE 1—CONCENTRATION OF ANTIKNOCK AGENTS IN VARIOUS CUTS MADE BY STEAM DISTILLATION

Cut No.	Tetraethyl Lead, Cc. per Gal.	Benzol, Per Cent
1	0.0	55
2	0.0	100
3	0.5	100
4	3.2	55
5	13.2	0

The natural remedy for such a condition was to supply sufficient heat to dry out the fuel mixture as quickly as possible after carburetion. Jacket temperatures raised to 300 deg. fahr. considerably reduced the time lag. Better results were secured by use of a short steam-jacketed pipe inserted between the carbureter and the cylinder-block. This seemed to be the answer, for the time-lag was reduced so much by this step that fuels could be matched by ear when switching from one to another. Previously this had been impossible. Providing means to dry out the mixture between the carbureter and the cylinder-block on engines used for antiknock measurement is therefore apparently advisable.

This use of heat does not close the subject however, because several points still are not clear. For instance, an interval as great as 5 to 10 min. does not seem necessary to establish equilibrium in any stream or "puddle" of heavy ends that may be present between the carbureter and the inlet valve. Also, we might expect that whatever reduction in knock intensity might be found in going from one fuel to another of equal antiknock value should be followed by an increase in knock intensity when the change is made in the reverse order. In other words, if the increase in knock intensity is due to trapping some of the heavy ends containing most of the antiknock material, as it might be when changing to a gasoline containing tetraethyl lead, these same heavy ends should diminish the knock intensity when changing back to the fuel containing no tetraethyl lead. Expressed in still another way, a decrease in knock should always be either followed or preceded by an increased knock, according to the order in which the fuels are run. This was found to be true in case of Fig. 1, but other cases, such as the lower curve of Fig. 2, have shown that the knock may disappear no matter which way a change is made between the two fuels exhibiting this phenomenon of time lag.

Low-Temperature-Starting Development *of* Automobile Engines

By P. J. Kent[1]

Semi-Annual Meeting Paper

FAILURE to start, particularly at low temperatures, is responsible for a very high percentage of the service calls received by automobile clubs. This fact, in the author's opinion, indicates the importance of giving serious thought to the development of engines that will start at low temperatures without the exercise of skill or special knowledge on the part of the operator.

The various tests to determine the starting performance of the engine at 0 deg. fahr. and the method of interpreting the results are described. The program of tests includes determining the fuel supply to the carbureter, the cranking speed developed by a given type of starting-motor, the cranking capacity, the horsepower required to crank the engine, the proper gear-reduction between the starting-motor pinion and the engine flywheel, the starting-motor control-mechanism and selection of spark-plugs and ignition equipment. Following the conclusion of these tests, the various electrical units are chosen and the test engine equipped. The actual starting development, which is largely a question of designing the carbureter to give the correct air-fuel ratio under starting conditions and the best possible degree of atomization, follows. The size of the fixed vent-hole and the size or spring tension of the auxiliary valve in the choke disc giving the most satisfactory results is then incorporated in the carbureter specifications.

THIS paper deals with the testing and design of equipment which is of vital importance to assure successful starting of automobile engines at low temperatures; except that it will not attempt to cover that phase of the problem which has to do with the selection of proper lubricating oil. This has recently been covered in a very capable manner by other authors. Successful low-temperature starting depends upon the fulfillment of the following requirements:

(1) Positive supply of fuel to the carbureter

(2) Means for cranking the engine over a reasonable period of time and at a reasonable speed; the more positive the control of cranking, the easier will be the problem of starting

(3) Mixing the fuel and air in correct proportions for firing and delivering this mixture to the cylinder

(4) Igniting the mixture

These should be accomplished so far as possible without the exercise of skill or special knowledge on the part of the operator; that is, the starting should be foolproof.

For cold-starting development, certain standard conditions for making tests had to be adopted so that results and data collected over a period of time could be compared. Without having a precedent to go by, we had to use our own judgment in determining what these standard conditions should be, and they are given here, not with the implication that they are universal, but rather that they represent only the standards used in our laboratory.

(1) Air, oil and cooling solution in the engine; storage-battery; starting-motor and the engine under test to be thoroughly chilled to 0 deg. fahr. before each test is made.

(2) A grade of winter oil having uniform physical properties was used for all cranking performance tests. In virtually all cases, tests were made with fresh undiluted oil and then duplicated with similar oil diluted with 15 per cent of kerosene.[2] The latter probably represents the condition of oil in the average engine in winter time.

(3) A grade of gasoline having uniform distillation-properties.

(4) Battery performance as designated by Willard curves for new batteries at 0 deg. fahr.

(5) A uniform method of preparing the engine prior to making tests for cranking performance. This method will be described later.

Fuel Supply to the Carbureter

At present, using a fuel-pump to supply gasoline to the carbureter is almost universal practice, except where the fuel is fed by gravity direct from the gasoline tank. In choosing a fuel-pump, the pumping capacity at cranking speeds in relation to the engine requirements should not be overlooked. Measuring the fuel-pump capacity per stroke, while keeping the lift and delivery conditions the same as on the car, is very simple. If the full capacity of the pump is required, the carbureter float-bowl needle-valve must, of necessity, be wide open and the pump capacity should be measured accordingly.

The next step is to measure the fuel demand of the engine under the condition of operation for winter starting. All of our engines are developed to start with the choke fully closed and the throttle about one-third open, and this is the condition under which the fuel demand is measured at cranking speeds, ranging from approximately 20 to 60 r.p.m.

The fuel-pump capacity per stroke divided by two equals the capacity per engine revolution, and if this exceeds the engine demand per engine revolution throughout the range of cranking speeds, the pump is considered to be of ample capacity. If, however, the pump capacity is less than the engine demand, the next step is to determine the capacity of the carbureter float-

[1] M.S.A.E.—Chief electrical engineer, Chrysler Corp., Detroit.

[2] See THE JOURNAL, February, 1926, p. 164.

bowl and divide it by the difference between the engine demand per revolution and the pump capacity per engine revolution. The result will be the number of revolutions the engine can be cranked until the float-bowl is drained. Unless the fuel-pump is to be the limiting factor, this figure should agree fairly closely with the number of revolutions that the engine can be cranked by the battery before its terminal voltage is reduced to approximately 3 volts, otherwise good judgment would seem to indicate the advisability of installing a fuel-pump having greater capacity at cranking speeds.

Developing the Cranking Performance

The operating characteristics of gasoline engine, fuel, lubricants and electrical equipment are such that, if the cranking performance of the engine is developed to take care of good starting at cold temperatures, it will

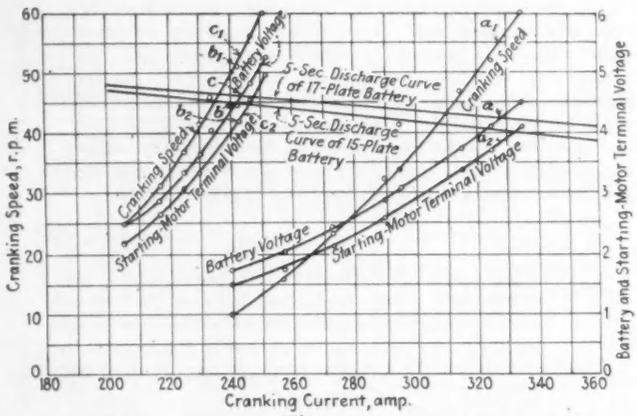

FIG. 1—CRANKING-SPEED TESTS ON AN EIGHT-CYLINDER ENGINE WITH THREE COMBINATIONS OF STARTING-MOTOR AND BATTERY

The Tests Were Made at a Temperature of 0 Deg. Fahr. and with Oil That Had Been Diluted with 15 Per Cent of Kerosene. Below Are Given Particulars of the Various Combinations Tested, the Cranking Current, the Voltage at the Starting-Motor and Battery Terminals for Various Cranking-Speeds together with Predetermination of Actual 0-Deg. Cranking-Speed for the Starting-Motors Used in the Test and Any Desired Battery for Which the 0-Deg. 5-Sec. Discharge-Characteristics Are Known

Combination	*a*	*b*	*c*
Gear-Reduction Type	Direct	Back Geared	Back Geared
Ratio	9:115	11:115 and 14:29	11:115 and 14:29
Plates in Battery	17	15	17
Cranking Current, amp.	328.0	242.5	244.0
Starting-Motor Voltage	3.85	4.15	4.25
Cranking Speed, r.p.m.	55.0	51.5	53.0

The Intersection of the 5-Sec. Battery-Discharge Curves with the Battery-Voltage Curves at *a*, *b* and *c* Gives the Battery Voltage for the Corresponding Combinations Tested. Projecting These Points To Intersect the Cranking-Speed Curves at a_1, b_1 and c_1 and the Starting-Motor Terminal-Voltage Curves at a_2, b_2 *and* c_2 Gives the Speed at Which the Engine Would Be Cranked and the Starting-Motor Terminal Voltage for the Corresponding Battery, Starting-Motor and Great-Reduction Combination; and on the Base-Line the Cranking Current Is Indicated

automatically be satisfactory for summer starting. The whole problem then is to arrive at some test-condition which is sufficiently severe to represent the starting problem of, say, 98 per cent of the car owners during the winter months. This figure is arbitrary, and I merely want to point out that we shall always have exceptional cases, protection against which is commercially impractical. Without attempting to fix a definite standard, we always strive to develop our cranking to give a minimum speed of 40 r.p.m. after the engine, oil and battery have stood for 24 hr. at a temperature of 0 deg. fahr., the oil in this case to be our standard winter-test oil with 15 per cent of kerosene dilution, and the battery to be fully charged.

When a new car-model is developed in our engineering department, experimental engines are built up for the road cars, the dynamometer laboratory and the cold room. The engine for the cold room is first delivered to the dynamometer laboratory and run in until the friction horsepower is reduced in accordance with our standard practice. It is then mounted on one of the cold-room test-stands and the old oil drained out and replaced with the standard cold-test oil diluted with 15 per cent of kerosene. The engine is then run outside of the cold room at about 1000 r.p.m., without load for approximately 10 min., or until the cooling water reaches a temperature of 150 deg. fahr. The engine is then stopped by shutting off the fuel supply to the carbureter, so that all gasoline will be drained from the carbureter. This run thoroughly mixes the oil and distributes it to the bearings, cylinder-walls and other parts. The engine is then placed in the cold room at 0 deg. fahr. and allowed to stand for 24 hr., when it is ready for the cranking test. From experience, we know approximately which type of starting-motor an engine should require and the gear reduction between the motor and engine flywheel, and the engine is so equipped for the initial cranking-test.

Cranking-Speed Test

This test consists of cranking the engine with the starting-motor, using a 6-volt battery in series with a variable-voltage generator, the voltage of which can be varied from practically zero up to 8 or 9 volts. This generator is located in the electrical laboratory with about 60 ft. of cable between it and the starting-motor. The engine is first cranked with the battery discharging through the starting-motor, the interconnecting cables and the armature circuit of the variable-voltage generator, the field of which is not excited. This gives about 1½ volts across the starting-motor terminals. The field is then excited and the voltage stepped up ½ volt at a time until the starting-motor voltage reaches 6 volts. For each voltage we observe the starting-motor current, the voltage across its terminals, the oil temperature and the cranking speed. Curves are then plotted, using current as a base line and starting-motor voltage and speed as ordinates.

Fig. 1 shows the results of cranking-speed tests on an eight-cylinder engine with two different starting-motors and illustrates the predetermination of engine cranking-speed with three combinations of starting-motor and battery. The electrical characteristics of a series-field starting-motor are such that the starter torque is a direct function of the starting-motor current and the speed is a direct function of the starting-motor terminal-voltage, minus the *IR* drop in the motor.

Above the observed starting-motor-voltage curve is plotted the required battery-voltage curve for the corresponding cranking speeds. The points for this curve are calculated by adding to the former voltage the drop in the car ground-circuit and the starting-motor cables. The resistance of this circuit on the average Chrysler car is 0.0012 ohms, and this factor multiplied by the current for each test point gives the voltage drop in the line. Adding the result to the starting-motor voltage gives the required voltage at the battery to crank the engine at the corresponding observed speed. The

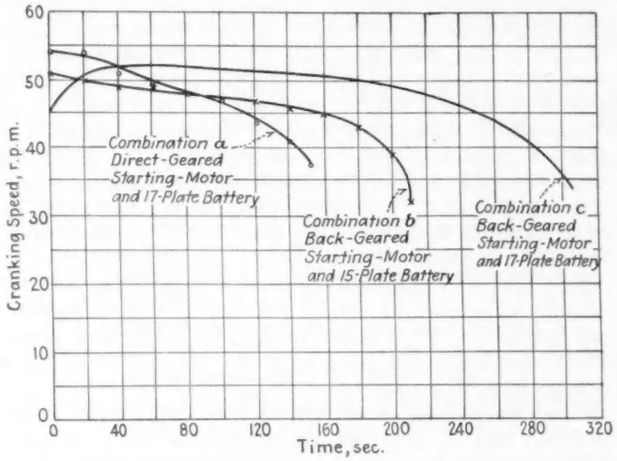

FIG. 2—RESULTS OF THREE CRANKING-CAPACITY TESTS MADE ON AN EIGHT-CYLINDER ENGINE

The Temperature and Oil Conditions and the Starting-Motor and Battery Combinations Were the Same as for the Cranking-Speed Test of Fig. 1. The Results of the Tests Are Given Below

Combination	*a*	*b*	*c*
Current at Start, amp.	365	245	270
Current at Finish, amp.	310	215	205
Starting-Motor Voltage at Start	3.65	4.25	4.20
Starting-Motor Voltage at Finish	3.00	3.00	3.00

next step is to plot on the same curve sheet the 0-deg. 5-sec. discharge-curves for the various batteries to be considered. The intersection of the curve representing required battery-voltage and the battery 5-sec. discharge-curve or the curve representing battery voltage available gives the cranking current for that particular battery, and projecting this point on the cranking-speed curve gives the speed at which that battery would crank the engine with the particular starting-motor and gear reduction under test.

If other types of starting-motor or different gear-reductions are to be tested, the equipment is changed in the cold room and the test repeated. As a rule the tests are then checked back the following day and the various starting-motors tested in the reverse order, although we do not find that the cranking torque of the engine varies materially when three or four tests are made on the same day, provided all gasoline is drained from the system as previously mentioned.

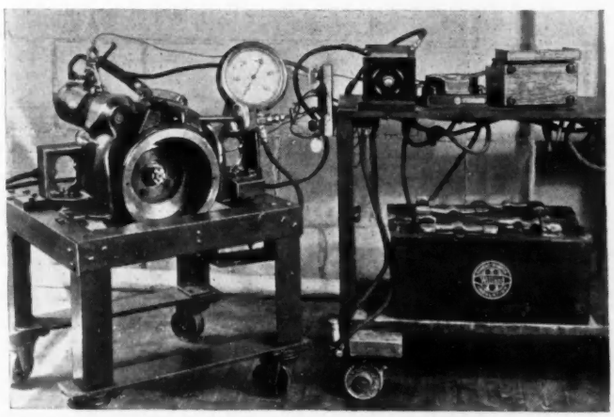

FIG. 3—TEST STAND FOR CALIBRATING STARTING-MOTORS IN TERMS OF TORQUE AT THE ENGINE CRANKSHAFT

After the tests with diluted oil are completed, the engine is removed from the cold room, run for a short time to warm the oil, and the diluted oil is then drained and replaced with fresh undiluted oil. The engine is prepared in the same way and then all tests are repeated. The fresh-oil tests represent a much more severe condition and, in general, the cranking speed with fresh oil will be roughly about one-half of what it is with the diluted oil.

The data collected from the foregoing tests are sufficient to enable us to decide upon the correct equipment so far as initial cranking-speed is concerned, and as a rule we can decide on the equipment from these data or, at least, narrow down the various optional combinations of battery, starting-motor and gear reduction to two or, at most, three. Cost of equipment and relative cranking-capacity will determine the final decision.

Cranking-Capacity Test

The cranking-capacity test is made by preparing the engine for the cold room the same as for the cranking-speed test. However, the battery under consideration is connected directly to the starting-motor through a circuit equivalent to that on the car. The batteries for this test are previously tested for 5-sec. voltage and 300-amp. capacity at 0 deg. fahr. to make sure that they

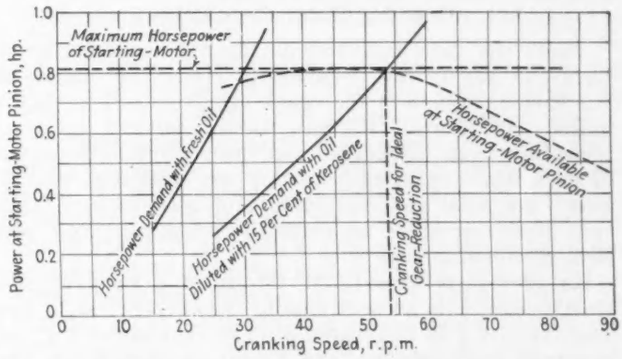
Power at Starting-Motor Pinion, hp.
Cranking Speed, r.p.m.
Maximum Horsepower of Starting-Motor
Horsepower Demand with Fresh Oil
Horsepower Demand with Oil Diluted with 15 Per Cent of Kerosene
Cranking Speed for Ideal Gear-Reduction
Horsepower Available at Starting-Motor Pinion

FIG. 4—HORSEPOWER REQUIRED TO CRANK AN EIGHT-CYLINDER ENGINE AT 0 DEG. FAHR.

These Curves Are Plotted To Show Horsepower Required To Crank the Engine at Various Speeds in Terms of Horsepower at the Starting-Motor Pinion; also Horsepower Available from the Starting-Motor at the Pinion, and Indicate the Method of Determining the Ideal Gear-Ratio, as well as Cranking Speeds That Would Be Obtained from the Starting-Motor for Which the Curve Is Plotted

are up to specifications. The engine is then cranked continuously until the voltage across the starting-motor terminals is reduced to 3 volts.

The current draw and the starting-motor terminal voltage, which is practically the same as ignition voltage, are observed at the start and at the end of the test. A Veeder counter checks the total crankshaft revolutions, and, in addition, the cranking-speed is checked at the start and at 20-sec. intervals until the test is completed.

Curves in Fig. 2 show the results of three cranking-capacity tests made on an eight-cylinder engine, using the same three combinations of starter and battery equipment as for the cranking-speed-test curves shown in Fig. 1. While the initial cranking-speeds are about the same in all cases, the length of time for which the engine can be cranked by the different combinations of

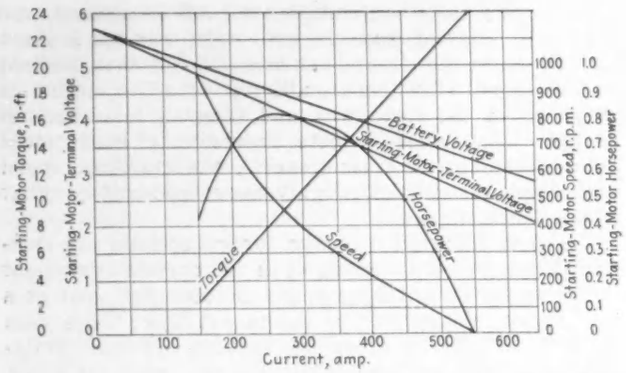

FIG. 5—STARTING-MOTOR PERFORMANCE AT 0 DEG. FAHR.

These Curves Are for a Back-Geared Starting-Motor and a 17-Plate Battery, the Same as in Fig. 4. The Resistance of the Starting-Motor Was 0.0047 Ohms and That of the Starting-Motor Circuit Was 0.0012 Ohms

equipment shows a wide variation. As will also be noted from the curves in both Figs. 1 and 2, the current draw is less and the voltage at the starting-motor as well as at the ignition is greater in the case of the back-geared starting-motor tests.

Engine-Cranking Horsepower and Determination of Starting-Motor Gear-Ratio

From the data collected during the cranking-speed tests the horsepower required to crank the engine at the various speeds in the cranking range can be determined. If several different starting-motors and batteries are to be considered and the performance curves of each motor with each battery are available, we can select the ideal gear-reduction and predetermine to a very close degree of accuracy the cranking speed that each combination will give.

As previously stated, the torque of a series-wound starting-motor is proportional to the current; so, if the starting-motor is calibrated on a dynamometer for the torque-current relation, the torque in pound-feet can be substituted for amperes in the table of data collected during the engine cranking-speed test, and with these data the horsepower that is required to crank the engine at each speed can be computed in terms of starting-motor demand from the formula

$$\text{hp.} = 2\pi NRT \div 33{,}000$$

where

hp. = power required to crank the engine
N = engine cranking-speed in revolutions per minute
R = ratio of speed reduction between starting-motor and engine flywheel
T = torque of starting-motor in pound-feet

If the actual engine-cranking horsepower is desired, the starting-motor torque as used above must be multiplied by a factor to allow for loss in the gearing between the starting-motor and the engine.

We have just completed the test stand shown in Fig. 3, which will calibrate the starting-motor in terms of torque at the engine crankshaft, and with it we hope to secure results that will enable us to make very accurate comparisons of engine-cranking torque. To determine the best gear-reduction, knowing the loss in the gears is not necessary. The horsepower required to crank the engine as computed from the formula is plotted against engine-cranking speed as shown in Fig. 4. From the starting-motor dynamometer test we observe speed and torque at the starting-motor pinion for different current values, using for each run a voltage at the starting-motor terminals which is equal to the 0-deg. 5-sec. discharge voltage of the battery minus the line loss on the car. From these data we compute the horsepower available and plot the complete performance curves of the starting-motor. For accurate work the starting-motor should be tested at 0 deg. fahr., or the normal-temperature test results should be corrected to that temperature by calculation, as has been done with the curves reproduced in Fig. 5. From the starting-motor horsepower curve we determine the maximum horsepower available and transfer it to the engine-cranking horsepower-demand curve.

The intersection on the horsepower-demand curve will indicate on the base line the maximum cranking-speed that can be expected from the starting-motor and battery under consideration. This speed is divided into the speed of the starting-motor at the point of maximum horsepower (see Fig. 5) and the result is the ideal

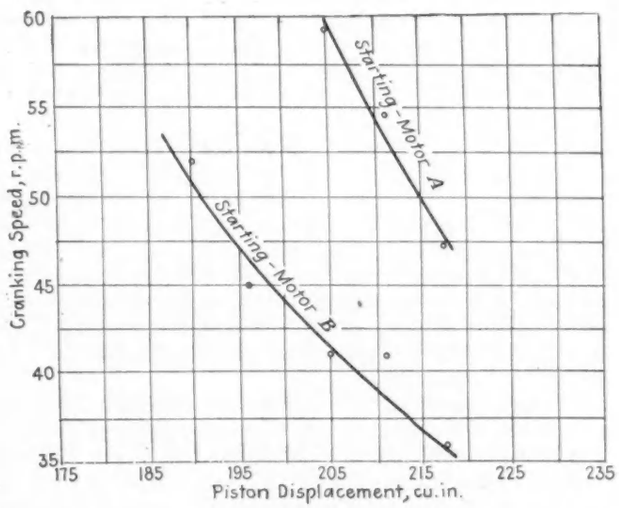

FIG. 6—RELATION BETWEEN CRANKING SPEED AND PISTON DISPLACEMENT

These Curves Present a Comparison of Cranking Speeds for Five Six-Cylinder Engines of Similar Design and Approximately the Same Compression-Ratio. Both Starting-Motors Were of the Direct-Geared Type with a Gear-Reduction Ratio of 9:115. A 13-Plate Battery Was Used in All Tests, Which Extended over a Period of 1 Year. Starting-Motor *A* Had Four Poles Wound, While Starting-Motor *B* Had Field Coils on Only Two Poles

gear-ratio for best cranking under the condition adopted. With a direct-geared starting-motor, the range of gear reductions available is rather limited and, even with back-geared starting-motors, adopting the ideal ratio is not always commercially practical. However, if the checks as outlined were made on all engines, I am very sure that better winter cranking-speeds would result, with less drain on batteries, and at the same time give us higher voltage at the ignition.

In Fig. 6, curves showing the relation between 0-deg. fahr. cranking-speeds and piston displacement are plotted for five six-cylinder engines of similar design and approximately the same compression-ratio. The tests on these engines were not all made at the same time and actually extended over a period of a year. The

same size of battery was used in each case. One curve shows the cranking speeds, using a starting-motor in which only two poles were provided with field coils. The other had four poles wound.

From the great volume of cranking data that has been accumulated in our laboratory we can say in general that

(1) The larger the engine, the more difficult is the problem of winter cranking.

(2) For any given starting-motor, increasing the size of the battery will not add greatly to cranking speeds but will materially increase cranking capacity.

(3) The cranking speed of an engine may vary over very wide limits, depending on the type of starting-motor and gear reduction used.

Starting-Motor Control-Mechanism

Starting-motor control-mechanisms as used today can be divided into three general classes which (*a*) automatically engage and disengage the starting-motor pinion, (*b*) manually engage and automatically disengage the pinion or (*c*) manually engage and disengage the pinion and have an over-running clutch that releases the armature in the interval between the time when the engine starts firing and the manual disengagement of the pinion.

Without entering into a discussion of the relative advantages and disadvantages of the three types of control, I will say that our experience has left no doubt

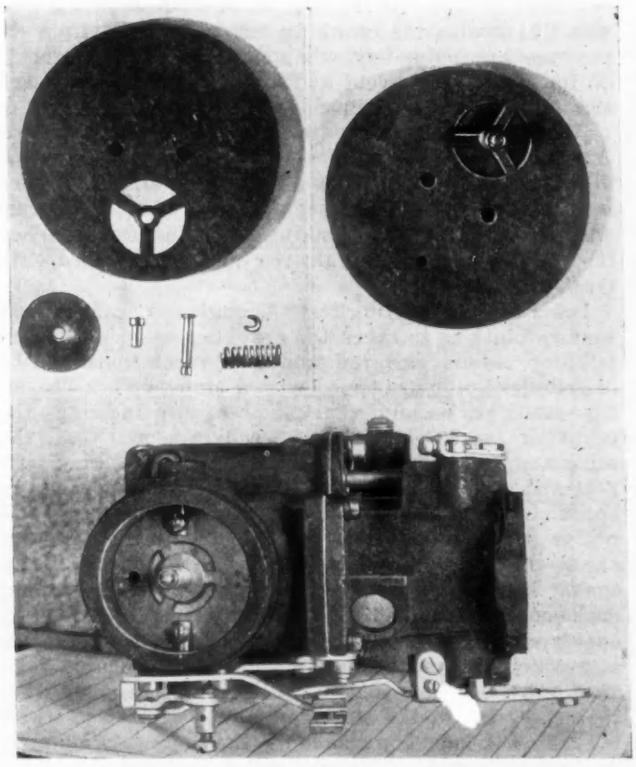

FIG. 7—TWO VIEWS OF THE CARBURETER USED IN THE WINTER-STARTING TESTS

The Upper Views Show the Choke Butterfly-Disc That Is Equipped with an Auxiliary Spring-Loaded Valve, the Opening of Which Is Controlled by the Vacuum in the Carbureter, and a Small Fixed Air-Vent. The Lower View Shows the Carbureter Completely Assembled

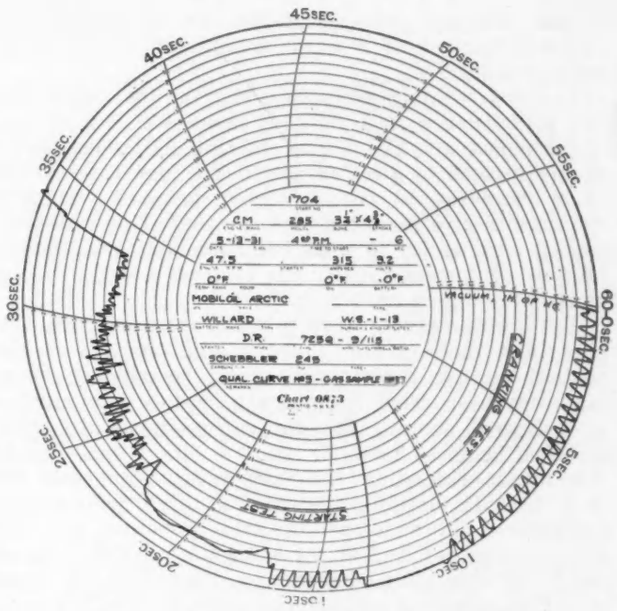

FIG. 8—INTAKE-MANIFOLD-VACUUM CHART

in our own minds as to the superiority of the third type so far as the winter-starting problem is concerned, particularly on the larger engines. When starting at low temperatures, very few engines will continue to run after the first explosion. However, with the positive control of the manual shift the pinion remains engaged and immediately picks up the engine until it is firing steadily. Further, in the case of the larger engines, while the torque from the initial explosion may momentarily exceed the cranking torque of the motor, it will not average as high, so that some outside assistance is required to keep the engine turning over until it is freed sufficiently to run on its own power. With the manual control, the starting-motor pinion can be kept engaged with the flywheel, making it possible for the starting-motor to supply this outside assistance.

Ignition for Cold Starting

Ignition systems now on the market are well standardized in design and, without exploring the field of the unconventional, the automobile engineer has very little choice in his selection of ignition equipment. While the importance of good ignition for winter starting cannot be overlooked, we can say without great fear of contradiction that almost any standard ignition-system on the market will fulfill the requirements for winter starting, provided it is in good condition. In other words, the servicing of the ignition system is the limiting factor as regards starting. Intensive research on the part of the ignition engineer, however, is needed to develop ignition that will not require frequent servicing. To be more specific, I believe that faulty contact points account for most of the winter-starting difficulties that can be attributed to the ignition system rather than any fault in the performance characteristics of the coil and distributor. If contact points become coated or pitted in a relatively short time, the fault may be lack of positive connections in the condenser. I am not in sympathy with any program for reducing the cost of the condenser that involves taking chances with the ground or live-lead connection to the condenser

plates. Further research should also be conducted on the development of a more satisfactory material for contact points.

In our laboratory we always test the ignition system for performance at 3 volts, to be sure that a suitable spark is available for winter starting. However, as the points become oxidized or pitted, the resistance across them increases, so that a higher primary voltage is required to give the same performance. This is another reason why we try to work out our starting-motor and battery equipment to give the highest possible voltage at the starting-motor terminals.

The ignition system very properly includes the spark-plugs and their correct selection and has a very important bearing on winter starting. Spark-plug manufacturers have tried for years to reduce the number of designs to accommodate the various types of engine, the ideal being to have one plug for all engines. To do this means extending the temperature range of the plug, that is, designing it so that high temperature encountered in wide-open-throttle operation will not cause preignition and at the same time the lower temperatures encountered in starting, idling and low-speed operation in winter will not cause the plug to foul with carbon. The latter condition results in hard starting and should be guarded against. We have never been able to work out a satisfactory test to predetermine whether a spark-plug will or will not foul in a given engine.

Our method of selecting spark-plugs is to adopt one that will not break down from preignition when operating for 10 min. in the engine under full load at 2000 r.p.m. with the cooling water at 200 deg. fahr. and the spark advanced 50 per cent above normal but will break down under the same condition with the spark advanced 75 per cent above normal for that speed. Allowing for a factor of safety, we feel that this test will indicate the hottest spark-plug that can be used in the engine without danger of preignition, and at the same time those so selected have kept us reasonably free of fouling in winter.

Recently we cooperated with Hector Rabezzena, chief spark-plug engineer of the A. C. Spark Plug Co., on a series of tests in which the temperature of the spark-plug was measured at the tip of the porcelain inside the combustion-chamber for different operating conditions. The conclusion drawn was that 14-mm. spark-plugs have a wider operating-temperature range than the 18-mm. plugs, and we believe that if plugs of the former size are selected by the process outlined, they will be less subject to fouling than the 18-mm. plugs while retaining the same factor of safety as regards preignition. The 14-mm. spark-plugs are now in service on the Chrysler Eight. However, our field experience is not sufficient as yet to state whether results in actual practice will verify the test conclusion. Maintenance of a standard gap at the spark-plug electrodes is also very essential for good winter starting, and indications to date are that gap growth with 14-mm. spark-plugs is about 25 per cent less than with the 18-mm. plugs.

Winter-Starting Development

At the conclusion of the low-temperature cranking-tests and the dynamometer tests for selecting spark-plugs and ignition timing, the electrical units are decided upon and released and the test engine equipped accordingly. The engine is then ready for actual starting development, which is mainly a question of designing the carbureter to give the correct air-fuel ratio under starting conditions and the best possible degree of atomization.

As stated at the beginning of the paper, good starting should be as nearly automatic as possible. Ordinarily, considerable skill is required in manipulating the choke and throttle controls to secure a mixture that will keep the engine running after the initial explosion. If the choke is closed too much, the engine will load up, and, if opened too wide, the mixture will be too lean to keep the engine running. All of our engines are developed to start with the manual choke-control fully closed and the throttle about one-third to one-half open. The choke butterfly-disc is equipped with an auxiliary spring-loaded valve, the opening of which is controlled by the vacuum in the carbureter, and a small fixed air-vent (see Fig. 7). At cranking speeds, the vacuum is insufficient to open the auxiliary valve, but, as soon as explosions occur, the vacuum increases, causing the valve to open and admit just the right volume of air to produce a mixture that will keep the engine running. Until the engine is running fairly steadily on its own power, adjusting the manual choke-control is not necessary. During the start, the starting-motor control-pedal is always kept fully depressed until the operator is sure that the engine is going to run. The pedal is then released and, as the engine frees up, the choke is gradually opened. Some of the carbureters are not fitted with a choke butterfly-valve; however, the construction is developed to give the same final result. As was the case in the cranking tests, we know from experience approximately what the specifications should be for the fixed air-vent and auxiliary choke-valve, and the carbureter is equipped accordingly.

The engine is started twice a day for several days. At the beginning of the starting tests the engine is filled with fresh oil and, as a result, the cranking speed is slow. Dilution increases for each successive start and, consequently, the cranking speed increases. When the speed becomes too high, the oil is replenished with fresh oil.

Prior to each starting test the engine is cranked over four revolutions to check the cranking speed. The distributor cap is removed and two revolutions of the distributor rotor are timed with a stop-watch. The intake-manifold vacuum chart, Fig. 8, also indicates the cranking speed. During the cranking-speed test, the recording voltmeter-ammeter checks the cranking current and starting-motor voltage. During the cranking-speed check the carbureter is dry, so that gasoline will not be drawn into the engine. Following the cranking check, the carbureter float-bowl is filled from a gravity tank. The engine is then ready to start. The manual choke-control is closed, the throttle set about one-third open and then the starting-motor pedal is depressed. A stop-watch is snapped and the recording vacuum-gage started by a remote-control switch simultaneously with the depressing of the storting-motor pedal. The starting-motor is kept engaged until the engine is running on its own power. The stop-watch indicates the time required to start, and the vacuum-gage chart gives a further check. After the engine is started, it is allowed to idle at about 500 r.p.m. until the cooling-water temperature reaches 160 deg. fahr. The gasoline is then shut off and the float-bowl drained.

All cranking and starting data are recorded in the center space of the vacuum-gage chart, and these data.

together with the vacuum curve, give a permanent record of each start. When several starts have been made, a curve is plotted, as in Fig. 9, showing the relation between the time required to start and the cranking speed.

From the cranking-speed tests made with undiluted and 15-per cent kerosene-diluted oil we take the cranking speed to be expected from the engine and plot vertical lines through these speeds on the starting-time curve. Their intersections will give the time required to start the engine at 0 deg. fahr. with the actual equipment as released.

If the carbureter we start with does not give a satisfactory starting curve, it will be modified, changing the size of the fixed vent-hole or the size or spring tension of the auxiliary valve in the choke disc. The carbureter is sent to the carbureter research department for a flow test with each choke-vent-and-valve combination to determine the full-choke starting-air and mixture-quality curves, a set of which are reproduced in Fig. 10. These curves, together with the starting-test results, usually indicate the next logical step to be made in carbureter development. When the best combination is finally determined, the full-choke starting-air and mixture-quality curves are written into the carbureter specifications. To the best of our knowledge, the Chrysler Corp. is the only company following this practice.

In recent months we have devoted considerable research to the problem of getting a higher degree of atomization in the gasoline mixture delivered to the manifold and, experimentally, have been able to reduce the starting time 50 per cent. As this phase of development is still in the experimental stage, it cannot be discussed at this time.

Experience in developing carbureter mixture-ratio for winter starting has indicated that a reasonably

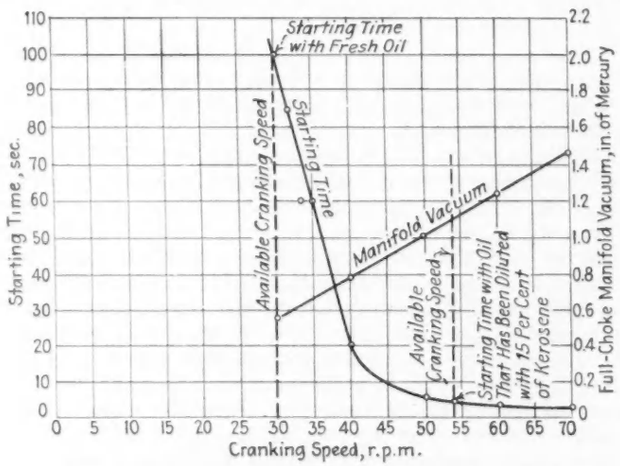
Starting Time with Fresh Oil
Starting Time
Available Cranking Speed
Manifold Vacuum
Available Cranking Speed with Oil That Has Been Diluted with 15 Per Cent of Kerosene
Starting Time, sec.
Full-Choke Manifold Vacuum, in. of Mercury
Cranking Speed, r.p.m.

FIG. 9—STARTING TIME-CRANKING SPEED CURVE

The Results Shown Were Obtained on a Six-Cylinder Engine Having a 5.2:1 Compression-Ratio. The Starting-Motor Was of the Direct-Geared Type with a 9:115 Gear-Reduction and the Battery Had 15 Plates. The Cranking Speeds To Be Expected from the Engine with Fresh and Diluted Oils, from the Results Obtained in the Cranking-Speed Tests, Are Located on the Base-Line of the Chart. If These Points Are Projected Vertically To Intersect the Starting-Time Curve, the Time Required To Start the Engine Can Be Read on the Scale at the Left by Projecting the Point of Intersection Horizontally

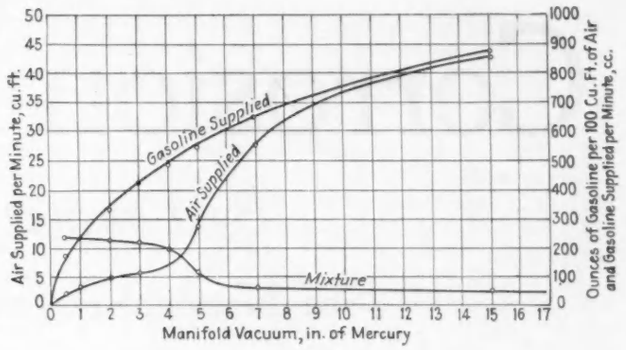
Gasoline Supplied
Air Supplied
Mixture
Air Supplied per Minute, cu. ft.
Ounces of Gasoline per 100 Cu. Ft. of Air and Gasoline Supplied per Minute, cc.
Manifold Vacuum, in. of Mercury

FIG. 10—FULL-CHOKE STARTING-AIR AND MIXTURE-QUALITY CURVES

These Curves Were Obtained from the Carbureter Used for the Starting Tests, the Results of Which Are Shown in the Curves of Fig. 9, the Throttle Being Half Open and the Choke Disc Held in the Closed Position

definite mixture must be supplied for each engine if the best starting results are to be obtained. While the mixture ratio will vary with different engine designs, the variation for the engines that we have tested does not cover a very wide range. This leads to the belief that, in terms of the actual vaporized mixture in the combustion-chamber, a single definite mixture-ratio exists which, if possible to secure, would give the best winter-starting results in all engines, just the same as applies in the case of a warmed-up engine running under full load.

The full-choke mixture at the carbureter as determined above will probably not hold good for the mixture in the combustion-chambers of the individual cylinders, as manifold distribution will cause variations. The manifold, valves and combustion-chamber design probably also play a part in the actual degree of vaporization of the fuel, so that the carbureter can only compensate for and average the various factors involved. This accounts for the different mixture-ratios required by different engines to give the best starting. The belief stated should not be regarded as a conclusion, because our data cover only a very limited number of engine designs.

Conclusion

In conclusion, I should like to point out that winter-starting development should be given very serious study, as the records of automobile clubs show that a high percentage of their calls for service originate on account of failure to start, particularly in winter. I have attempted to cover methods of test and interpretation of results in this paper and time would not permit the presentation of any considerable volume of data. However, we are gradually accumulating comparative data on cranking and starting different sizes and types of engine, which I hope to present at a later date. In closing, I want to acknowledge the assistance of A. J. E. Roualet, who is in direct charge of our cold-room testing, for the preparation of starting and cranking data; of R. W. Eddy for starting-motor test-data and of Fred and Tom Ball for their cooperation in testing the carbureters used in our development.

Corrosion Prevention

By Lessiter C. Milburn[1]

19th National Aeronautic Meeting Paper

MEANS for protecting aluminum from corrosion is the principal topic discussed by the author. In this connection the theory of corrosion is analyzed and various protective coatings, such as paints, oils and greases, and the metallic, chemical and electrochemical types are commented on.

Corrosion prevention, in the opinion of the author, is an obligation that rests primarily upon the aircraft manufacturer, who should provide a complete system of corrosion protection, either by design or by manufacturing processes, which will be effective for several years and also supply a foundation on which the operator can overhaul the aircraft at the minimum expense.

The German methods of protection against corrosion, as described by one of the discussers, do not require any heat-treatment of the metal by the manufacturer, the material being used as it comes from the mill and the sections being drawn through a set of rolls rather than through dies under tension. When heat-treating rivets to prevent corrosion, said another speaker, they should be quenched quickly. Proper heat-treatment of the metal, its correct preparation for painting and securing good adherence of the paint are necessary. The results obtained from Alclad metal in service were commented on. Other topics brought out in the discussion include the possibility of rustless steel replacing duralumin; the use of zinc as a corrosion preventive in airplane construction, the same as this metal is used in shipbuilding; and data on some of the new foreign alloys that have recently been developed for use in aircraft construction.

AIRPLANES are designed for actual loads encountered in flight, landing, taxying and other maneuvers as nearly as they can be determined, plus a small margin to take care of variations in material, workmanship and other indeterminates. Present safety factors are based largely upon standards set up during the last war. Airplanes designed for war use were not expected to have a long life, and maintenance expense was not a prominent consideration. Now the purchaser of airplanes is vitally concerned with the life expectation and maintenance cost. I have never known a margin of safety to be applied in anticipation of corrosion, nor should such an allowance be necessary if proper measures are taken. Nevertheless, a small amount of corrosion can produce an important decrease in strength. Providing adequate protection is worth while because any airplane may sooner or later be subjected to corrosive conditions. Ordinary inspection does not permit examination of concealed parts and therefore the protection must be adequate on all parts.

Theory of Corrosion

Aluminum and its light alloys undergo a chemical corrosion process. Any solution that will combine with aluminum to form aluminum hydroxide will cause corrosion, those containing fluorides, hydroxides, chlorides or peroxides being particularly active. Minute quantities of chlorides or hydroxides may sometimes be found in fresh water and produce unexpected corrosion. Aluminum sheet stored where it may become wet or damp sometimes corrodes.

As sea water and seacoast atmosphere contain chlorides, the worst cases of corrosion have been encountered in coastal places. Aluminum chloride is first formed and, with moisture present, is converted to aluminum hydroxide, the familiar white powder of corrosion. Minute quantities of hydrochloric acid are simultaneously liberated, which further react upon the aluminum, forming a continuous cycle of corrosion from a very small quantity of the chloride.

Although the water present may be only dampness, or even vapor, the reactions are the same as if the materials were dissolved in a liquid solution and the same principles of solution apply. According to modern solution theory, the solution of a salt, an acid or a base in water contains part of the dissolved material in a split-up form; that is, the molecules are split into simpler units, called ions, carrying electric charges that will seek the nearest opposite pole if the circuit is externally completed, and the solution action is greatly accelerated. In the case of aluminum alloys, the aluminum is continuously taken into solution and the aluminum hydroxide is expelled, together with hydrogen, chlorine or other gases. These gases produce the paint blisters that eventually crack open and leave the surface exposed.

Corrosion in aluminum alloys is usually a product of solution and electrolysis combined. The attack may be on the surface or between the microscopic grains of the metal, hence the name intergranular. The grains of the metal are rich in aluminum, while the binder constituents that hold the grains together have a much lower aluminum-content. When exposed to a corrosive agent, the effect is the same as if two dissimilar metals were present, and the attack proceeds along the grain boundaries, causing considerable reduction in strength and elongation with little visible evidence. Quenching in hot water after heat-treating makes common aluminum alloys of the copper-magnesium class more susceptible to intergranular attack, and cold water should always

[1] Vice-president and chief engineer, Glenn L. Martin Co., Baltimore.

be used. Corrosion may also occur by pitting, and in this case also the attack is due to dissimilarities between adjacent portions of the metal.

Pure unalloyed metals resist corrosion better than do metallic alloys. Chemically pure iron, of which good wrought iron is an approximate example, resists corrosion better than do ordinary steel alloys. Only when the chemical affinity of the alloying elements is completely satisfied do we find non-corrosive alloys. The electrolysis theory explains why this is so, and whenever dissimilar metallic constituents are brought together in the presence of water, an electric potential is set up between them, due to the difference in their solution pressure, or tendency to dissolve. If the water or moisture contains salts, acids or bases, it acts as an electrolyte and promotes electrolytic action. If the water contains chemicals that react with aluminum, the action is accelerated, as in the case of sea water which contains sodium and calcium salts. Measurements have been made recently of the difference in electric potential between pure aluminum, aluminum alloys and other metals[2]. In a solution of normal sodium-chloride the external potenials given in Table 1 were measured.

TABLE 1—POTENTIALS DEVELOPED BY THE IMMERSION OF TWO DISSIMILAR METALS IN A NORMAL SODIUM-CHLORIDE SOLUTION

	Aluminum Alloy 17*ST*	Aluminum 99.2 Per Cent Pure	Steel	Zinc
Aluminum Alloy 17*ST*	....	0.150	....	....
Aluminum 99.95 Per Cent Pure	....	0.026	....	....
Brass	0.381	0.538	....	0.801
Copper	0.375	0.510	....	....
Iron	....	0.150	....	....
Steel	0.101	0.039	....	....
Zinc	0.483	0.338	0.390	....

Further tests were made using hydrogen peroxide in the salt solution without any material change in the potential. The same result was obtained with dilute ammonium-chloride. The order of results is substantially in accordance with the location of the various metals in the electromotive series, with due allowance for the differences between pure metals and their alloys. Apparently the potential between aluminum alloys and other metals exists even in pure water, only a small quantity of salt or acid being needed to start the action, the rapidity of which depends upon the chemical affinity of the aluminum for the elements present in the water. Corrosion is also accelerated by heat.

Not long ago tests were conducted in the laboratories of the Martin Company to determine the potential between aluminum alloy 17*ST* and an anti-corrosive steel alloy containing 18 per cent of chromium and 8 per cent of nickel. Plates of these metals were mounted in dry wood, 30 in. apart and immersed in sea water. With no other connection the rate of corrosion of the aluminum alloy was normal, but with a separate metal connector outside the liquid the rate was visibly increased. The potential measured was 0.25 volt with the connector. Both metals were bare, without paint, plating or anodic coating. This experiment was made to check possible trouble from a duralumin hull used in connection with non-corrosive steel wing-tip pontoons. The hull and pontoons were to be connected as usual by metallic structure and both immersed in sea water. The indications are that rapid corrosion can be expected if the protective coatings are scraped off by service use. The same conditions may occur in the indiscriminate use of these two metals in other parts of airplanes, particularly when in close contact. The fact that the 18 and 8 alloys are non-corrosive does not alter the electrolytic conditions, and the same precautions should be taken as with any other dissimilar metal.

The principal reason that an alloy of metal corrodes more rapidly than does a pure metal is that the former may contain dissimilar metals within itself, while the latter is homogeneous throughout. Pure metals merely dissolve without the accelerating effect of electrolysis. Furthermore, pure metals dissolve only in chemical solutions that strongly attack them and the attack is spread over all the surface, while alloy corrosion will be greatest at any spots where the electric current finds an easy path. Aluminum alloy 17*S* has much better resistance to intergranular corrosion when fully heat-treated than when it has been annealed or when partly heat-treated. Duralumin material, and particularly rivets, can go through the heat-treating operations without being fully treated, due to variations in temperature inside the furnace or bath, although pyrometers may be accurate and reading to the correct temperature. The greater attack on the un-heat-treated alloy probably is due to differences in potential and solution pressure between the aluminum-rich grains and the intergranular constituents brought about by quenching from above or below certain critical temperatures. A similar experience has been noted with the 25*S* alloy, which has better corrosion resistance after quenching and before artificial aging than it has when aged.

Effects of Corrosion

The chief effect of corrosion is reduction of strength and elasticity. So sure is this result that the extent of corrosion is now measured in terms of reduction of strength rather than by appearance or weight reduction, as formerly. The National Advisory Committee for Aeronautics has issued a series of reports on this question[3]. An interesting point accented in this investigation is the indication from laboratory tests that corrosion can be accelerated in service by high stresses in duralumin members and particularly when reversing or flexural stresses are involved. Vibration may be suspected as a contributing cause of rapid corrosion, for example, in engine cowling.

Other effects of corrosion may cause serious trouble in service. One of these is "frozen" threads and bearings. Contacts of dissimilar metals in bearings are often unavoidable, because of the tendency of most metals to seize when in bearing contact with metal of the same composition. Particular care should be taken to provide sufficient lubrication in such cases. Threads of tie-rods and bolts may also give trouble as a result of corrosion.

Another difficulty sometimes encountered is loss of electric conductivity due to corrosion of parts or joints. Precaution is necessary in this respect for airplanes that are bonded for radio. Aluminum conduit must be protected, especially at bends and connections, if short-circuits are to be avoided.

The drastic effect of corrosion upon strength makes corrosion prevention one of the primary responsibili-

[2] See *Transactions of the American Electrochemical Society*, vol. 56, p. 32.

[3] See National Advisory Committee for Aeronautics Technical Notes Nos. 282, 283, 284, 285, 304 and 305.

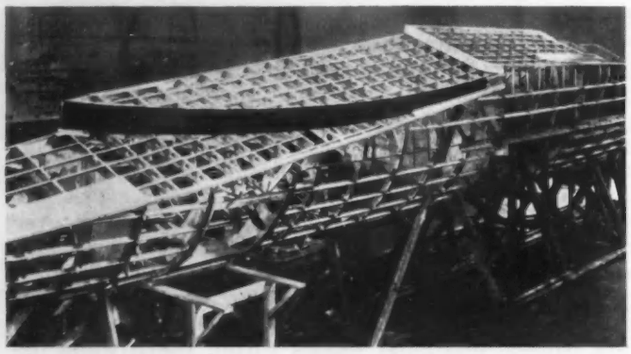

FIG. 1—UNCOVERED BOTTOM OF A METAL HULL SHOWING MANY POINTS REQUIRING HIGH-GRADE CORROSION PROTECTION

ties of the designing engineer. Elaborate study to determine loads and great care in calculating stress distribution become meaningless and wasted if the physical properties of structural materials are undermined by corrosion. Nor is careful design of details followed by the desired results if corrosion is permitted to interfere.

The three principal means of combating corrosion are: (*a*) material which in itself is inert to corrosive agents may be used, (*b*) suitable protective coatings may be applied and (*c*) design and manufacturing processes may be worked out to eliminate corrosive conditions.

Both bronze and non-corrosive steels are dissimilar to duralumin, and a considerable electrolytic potential exists between them, which will become active in the presence of any moisture that can serve as an electrolyte and particularly any water containing small quantities of sodium, potassium or calcium chloride, or their hydroxides, or any water containing small quantities of acid. The calcium chloride used to lay the dust in New York City subways is reported to be very destructive of aluminum parts. Calcium chloride, sometimes used for antifreeze purposes, may come in contact with duralumin parts, with the same bad results. Fresh-water rivers and lakes sometimes carry traces of chemicals that are sufficient to promote electrolytic action.

Protective Paints and Greases

The failure process of ordinary paint surfaces has been ascribed by Conrad F. Nagel, Jr., of the Aluminum Co. of America, as due to hygroscopic action. The paint surface, he explains, absorbs moisture, some of which passes through the paint, carrying with it whatever is dissolved therein. Corrosive action follows, liberating small quantities of hydrogen or chlorine gas, which raises the paint in large or small blisters, finally exposing the bare metal. That this theory is correct is evidenced by the complete success obtained with waterproof paints of bituminous nature.

The long and successful use of bituminous paints to protect wood from water suggested its use for aircraft structures. The Forest Products Laboratory has tested the resistance of asphalt paint to moisture penetration and has found that, whereas a covering of three coats of standard-grade spar varnish has a moisture-stopping efficiency of 60 per cent, the asphalt paint has an efficiency of 96 per cent, and the addition of aluminum powder increased this figure to 98 per cent[4]. The Martin Company has had opportunity to observe the protection given by aluminum bituminous paint on duralumin wing and tail frames and on floats and flying-boat hulls, similar to that shown in Fig. 1, and we have found that it provides a practically perfect protection from sea-water corrosion. An ordinary bituminous paint, without other pigments, is sensitive to sunlight and subject to shrinkage. To prevent checking and crazing, mixing a pigment with such paints is essential. Aluminum polished powder of about 140 mesh has been found very satisfactory for this use.

Unlike ordinary paints that are mixed in oils, bituminous paints are made up in coal-tar solvents with benzol or naphtha as the vehicle. The tarry pigment actually dissolves in the vehicle, whereas in oil paints no solution occurs but only an intimate mixture. As a result, the bituminous element of the paint will penetrate into any open surface, such as duralumin that has been sand-blasted or anodized, and, while the body of paint can be washed off a freshly painted panel of anodized duralumin with gasoline or benzol, the brown bituminous stain cannot be scrubbed off with any ordinary solvent.

For actual water operation, various grease, wax and oil coatings are sometimes used as an auxiliary protection on parts that are liable to abrasion, such as hull bottoms and chines. Aluminum powder is sometimes compounded with such coatings to overcome their greasiness. Beeswax with grease is sometimes used for underwater parts.

Exposed steel fittings, bearing surfaces, threads and the like are, in service, commonly coated with heavy grease to exclude moisture. This practice may be detrimental, however, if the grease is not chemically neutral or becomes contaminated with sea salt or other corroding agents.

Standard practice during the World War was to protect tubular steel members by zinc-plating the outside and filling the inside with blue-tinted varnish, then

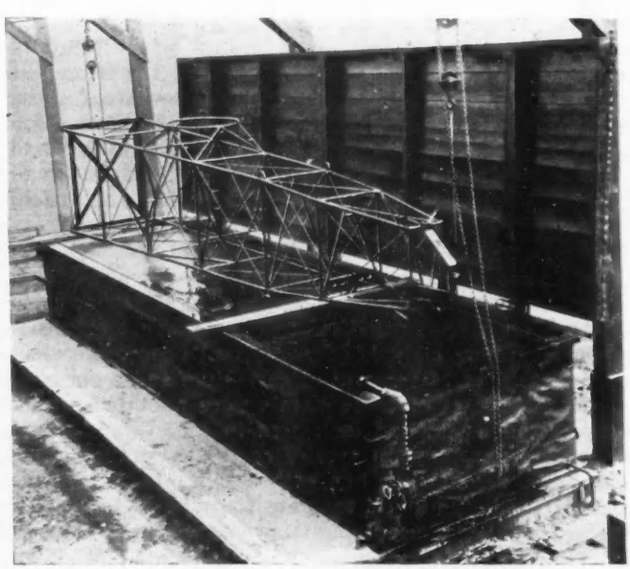

FIG. 2—DIPPING TANK FOR TUBULAR ASSEMBLIES

After Immersion in This Tank, Which Contains 3000 Gal. of Mineral Oil at a Temperature of 250 Deg. Fahr., the Assemblies Are Drained and Sealed with Water-Tight Metal Plugs and Asphalt Packing

[4] See Aluminum Bronze Powder and Aluminum Paint, by J. D. Edwards, pp. 57 and 58.

draining. Finally we noticed that the inside surfaces frequently corroded, even if the tubes were sealed air tight, and found that moisture had got into the tubes during the zinc-plating process. In 1921 the Martin Company undertook to remedy this condition and began a series of experiments that continued for more than a year and finally resulted in a method of filling such tubes with mineral oil heated to 250 deg. fahr. and then draining to drive out moisture and leave an oily surface[5]. The equipment used for this treatment is shown in Fig. 2, and Fig. 3 illustrates a typical assembly treated in this way. This practice was found to be very successful and has been adopted as standard practice throughout the industry.

Bakelite varnish, with or without pigment, is being used experimentally with promise of success. One specific use is on the inside surface of gasoline tanks. A coating for this purpose must be impervious to gasoline, benzol, ethyl fluid, traces of acid and moisture. Above all it must not age or disintegrate and fall off to cause deposits in screens or jets.

The most successful metal covering for duralumin has been one of aluminum developed by the Aluminum Co. of America and known as Alclad. In 1928 the Martin Company built two seaplane floats of Alclad which were used throughout the winter of 1928-1929 in Cuban waters. No intergranular corrosion was found. The surface, however, was generally corroded due to ordinary chemical dissolving action of the sea water on the pure-aluminum coating.

Precaution must be taken in selecting paint to cover Alclad, as a hygroscopic paint will permit corrosion of the pure-aluminum coating, with formation of bubbles and destruction of the paint. Similar precaution should be observed at any point where surface corrosion is undesirable or where difficulty may be encountered in proper cleaning prior to repainting in service maintenance operations. The difference in electric potential between the pure-metal surface and the alloy core is 0.15 to 0.20 volt. However, the flow of electrolytic current favors the alloy, which is protected at the expense of the pure-aluminum coating. The action on the coating produces no material reduction in strength or ductility of the alloy core, and it is so slow that the danger of total consumption of the coating during the life of the average airplane is slight.

[5] See Hot Oil Process, Glenn L. Martin Co. Test No. 4442.
[6] See *Metal Industry*, November, 1926, p. 472.
[7] See Bureau of Aeronautics, Navy Department, Specification SR-19.

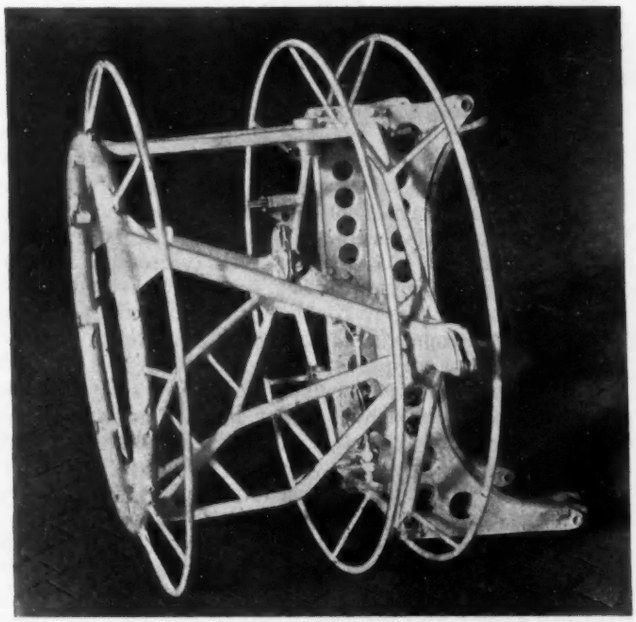

FIG. 3—TYPICAL STEEL-TUBING ASSEMBLY THAT WAS GIVEN HOT-OIL TREATMENT

After the Tubes Had Been Filled with Mineral Oil That Was Heated to 250 Deg. Fahr. To Drive Out Moisture and Leave an Oily Surface, They Were Drained. The Outside Was Subsequently Finished with Aluminum Enamel Paint

FIG. 4—EQUIPMENT USED IN THE ANODIC METHOD OF CORROSION PREVENTION

A Carefully Controlled Electric Current Is Passed through the Work, Which Is Suspended in a 3-Per Cent Solution of Chromic Acid. The Steel Tank Serves as the Cathode and the Work as the Anode, Hence the Name for the Process

Chemical and Electrochemical Coatings

The use of chemical solutions, either with or without electrolytic action, to produce a protective chemical coating on metal had been employed on iron and steel before aircraft construction began and was continued in aircraft work. Similar processes have been worked out for duralumin, resulting in chemical coatings of negligible thickness which serve as a protection from corrosion, either alone or as a base for paint[6]. One such process consists of immersing parts in a hot solution of sodium, potassium and chromium salts. The particular advantage of such methods is the fact that they coat both inside and outside of hollow parts and protect joints and crevices. Simplicity of application is a further advantage of these methods.

That aluminum oxidizes readily, forming a surface coating of aluminum hydroxide, is well known. Such a coating, if complete, tends materially to retard further corrosion of an aluminum surface, because the aluminum hydroxide is insoluble in water and is highly resistant to the passage of electrolytic currents. Efforts have been made to produce a coating that would clean and prepare duralumin surfaces for painting, plus a certain degree of protection, by oxidizing the surface in a 5-per cent solution of hot sodium-hydroxide, known as the caustic-dip process.

However, the method now in general use for this purpose is the anodic process[7]. This consists of suspending the work in a 3-per cent solution of chromic acid and passing a carefully controlled electric current through

it. An example of work being given this treatment is illustrated in Fig. 4. The work serves as the anode and the steel tank as the cathode, hence the name anodic treatment. The parts must previously be cleaned and rinsed in hot water. When parts are immersed the voltage is raised from 0 to 40 volts at a uniform rate over 15 min., is maintained at 40 volts for 35 min. additional and then increased uniformly to 50 volts for the final 5 min. The electrolyte is maintained at a little higher temperature than 100 deg. fahr. The usual precautions of plating must be observed, such as agitation of the electrolyte, maintenance of proper solution-strength and care to avoid burning or immersing other metals than aluminum in the solution.

The anodic-oxide coating is not in itself a sufficient protection from corrosion but has two outstanding merits. It provides an excellent absorbent surface for further paint coatings and is resistant to the hygroscopic moisture that is absorbed by the ordinary paints in service. The aluminum-hydroxide coating produced by the anodic treatment is essentially an insulator coating that prevents or retards the passage of electrolytic currents. It is also non-soluble in water and therefore protects the metal beneath from the ordinary chemical-solution action.

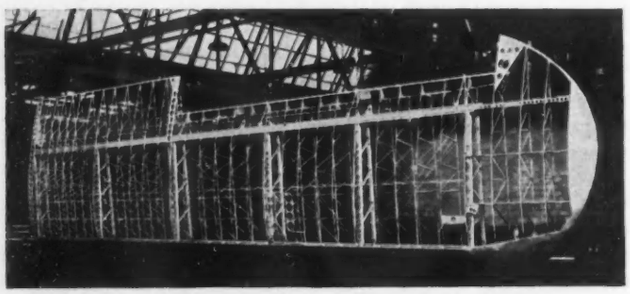

FIG. 5—AN ALUMINUM WING-FRAME AFTER LEAVING THE SPRAY BOOTH

Each Separate Piece Is Cleaned and Given a Coat of Aluminum Bituminous Paint. After Riveting, a Second Coat Is Applied by Dipping. A Final Spray Coat after Assembly in the Wing Frame Completes the Process

Corrosion Prevention by Design and Manufacturing Processes

In recent years we have found that considerable can be done to prevent corrosion by care and forethought in design and in manufacturing. Contact of dissimilar metals is now generally avoided, although in some cases this cannot readily be done. In such cases insulation should be provided in the form of gaskets set in asphalt paint or other waterproof material. Brass and duralumin react badly under corrosive conditions, but attention is not generally given to the fact that a difference in electrolytic potential exists between all dissimilar metals and even between different alloys of the same metal. The significance of this is that trouble may be encountered whenever this potential is greater than 0.15 volt. If the surrounding conditions are only slightly corrosive, no trouble will be encountered at voltages in excess of this, and the decision as to the degree of protection required must be made after consideration of both the existing potential and the conditions of service anticipated.

Dope destroys the paint film on the metal below. Anti-dope paints were formerly used to prevent this action, but they dry and crack. A very simple method consists in covering contact surfaces with paper-thin aluminum-foil, which not only protects the paint from attack by the dope but also protects the metal from corrosion.

Ventilation and drainage of all joints and pockets is very important. Open channels, angles and other shapes are superior in this respect to closed sections. Some years ago we observed from airplanes which had been in service that much of the corrosion which took place was in the joints between butting surfaces. Therefore we adopted a uniform practice of applying protective coatings to all separate pieces in detail prior to assembly, followed, of course, by the usual painting after assembly. The finishing process consists of cleaning all the separate pieces, after which they are painted with one coat of bituminous aluminum paint. Then they are riveted and the whole is dipped in the same paint for a second coat. After assembly in the wing frame, a final spray coat completes the process, a finished wing frame being shown in Fig. 5.

The practice of protecting all parts in the details is especially beneficial in flying-boat hulls and floats, where water is very likely to be taken in through cockpits or other openings and where it may lie along the keelson and bottom stringers for some time. Many joints are made up with wet paint between surfaces, in addition to detail painting, to seal the joints against moisture that might be drawn in by capillary attraction. The same practice is particularly good between joints of dissimilar metals. The light structure and many joints of the usual monocoque fuselage require similar attention to prevent corrosion from starting in the joints, as such corrosion is likely to be general and difficult to overhaul.

Heat-treating methods have considerable to do with corrosion of duralumin parts. Full heat-treatment is very necessary to obtain the best corrosion resistance of the most common aluminum alloy, 17*ST*. Furnaces in common use are either of the nitrate salt-bath type or the air-bath electric-furnace. The latter is very likely to have temperature variations in the heating chamber unless special means are provided to keep the temperature uniform. This is especially true if the heating chamber is large. We have tried both types in sizes of about 3 x 6 x 18 ft. and have found far less trouble in maintaining uniformity with the salt-bath type. Our present large furnace of the dimensions mentioned has a temperature variation of less than 5 deg. fahr. throughout all parts of the bath.

A diffiulty arises in the use of anodized rivets. The anodizing has been found to be of benefit in spite of the driving operation. Rivets may be heat-treated an indefinite number of times without injury. To avoid waste of rivets that have passed their time limit since quenching, they are gathered up and returned to the furnaces for re-heat-treating. However, if heat-treating is done in a salt bath, the molten salt penetrates the anodic coating and cannot readily be washed out, with bad effects on subsequent paint coverings. Therefore heat-treating rivets in an air-bath furnace or in a closed container is necessary. We found considerable variation in temperature in both cases. This was determined by mounting thermocouples in the center of each basket of rivets. In the air-furnace tests we had 30 thermocouples. In a high-grade electric air-fur-

nace extreme variations in temperature of nearly 100 deg. fahr. were found, showing that some rivets heated in such a way would not be fully heated, while others would be burned.

This investigation has had much to do with explaining why rivets were subject to erratic corrosion in previous years. A special investigation was made on rivets that corroded in service, as in Fig. 6, and all examined were found, without exception, to be improperly heat-treated; in fact, many were still in the annealed state. This condition was corrected by using a furnace of special design with automatically reversing air circulation. Rivets heat-treated since that time in this furnace have been free from any noteworthy corrosion. The same considerations apply to all heat-treatment of duralumin, and I desire to emphasize that what counts is the actual temperature of the work and not the pyrometer reading.

A further essential practice is to keep quenching water cold, either by circulation or cooling coils, the former being preferred as it assists in the dissipation of steam pockets in the work. Agitation of the work for the first few seconds after quenching is also of benefit for the same reason and also to promote rapid cooling.

Sealing duralumin and steel struts near the ends with water-tight metal plugs and asphalt packing is becoming standard practice, as such members may become corroded on the inside without the operator's knowledge. This practice is followed in conjunction with the internal oil treatment previously mentioned. The oil treatment is used on tubes that are hermetically sealed and on the end plugs on tubes that would otherwise be open.

The use of interior furnishings and upholstery, soundproofing and the like requires special attention to structure that is concealed. Precaution should be taken that no opportunity is left for moisture to collect or to be retained by fabric or padding in contact with metal.

Abrupt changes of cross-section should be avoided in places where vibration is apt to occur, because vibration or frequent bending will produce high stresses in the corners. Such stresses reduce corrosion resistance and furthermore tend to loosen paint coatings.

Special finishes are required at places where gasoline or battery acid may be spilled. For gasoline, we have had good results from aluminum-pigmented shellac. Bakelite varnish, suitably pigmented, also will be found useful.

Means should be provided for the convenient lubrication of bearings, sprockets, working threads and other parts, as they may become dry and corroded if lubrication is difficult. Copper tubes from such points to convenient exterior points, with lubrication fittings on the tube ends, have been found satisfactory. Inspection doors and access plates should be conveniently arranged and large enough to invite frequent inspection and refinishing if needed.

Cleaning and handling of work should be carefully done. Grease or dirt from handling after cleaning will result in poor adhesion of paint. Benzol should not be used for cleaning duralumin. Cleaning baths should be kept free from surface scum or the work will become greasy as it passes up through the surface.

Parts that are to remain in storage until needed also should be given special attention. We make a practice of flushing all fuel and oil tanks with light oil when they are to be put in storage as spare parts or shipped for any distance.

Severe corrosion may occur in shipments of airplanes to foreign countries over ocean and it is well to consider this fact in advance and provide adequate extra protection, drainage and packing of parts to prevent corrosion en route.

Corrosion Tests

Laboratory tests are very useful for comparative purposes. These are of five general types; (*a*) salt spray, (*b*) immersion test, (*c*) accelerated test, (*d*) corrosive-atmosphere test and (*e*) stress-corrosion method. The first is frequently used. When we first used this method we found that many protectives which would stand up 100 hr. in the spray would sometimes go to pieces in service. We decided to abandon the ordinary table-salt solution and use sea water instead. Being located in Cleveland, we had none, but through

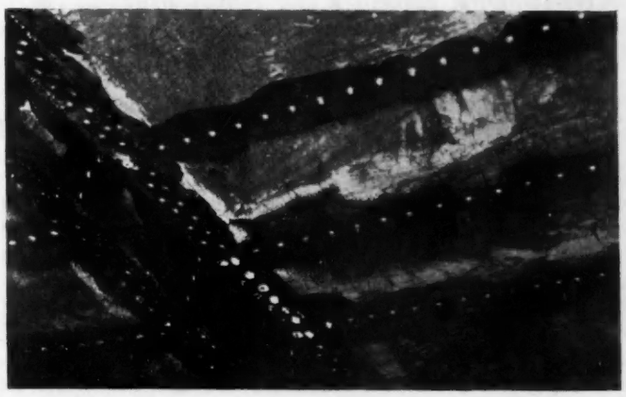

FIG. 6—SPECIMENS OF RIVETS THAT CORRODED IN A FLYING-BOAT HULL AS A RESULT OF IMPROPER HEAT-TREATING

the assistance of the Naval Air Station at Hampton Roads 15 bbl. of sea water was shipped to us. Our spray test immediately developed a much stronger corrosive attack, breaking down coatings in a few hours that had appeared satisfactory with table salt. However, in a few months the sea water became unusable because of dead marine organisms in it, and we began to manufacture our own sea water by redissolving evaporated sea salt, obtainable from any wholesale drug company. Its use instead of common salt is strongly recommended to avoid misleading results.

The immersion test is preferable to the spray because it promotes the development of electrolytic corrosion if the possibility of it exists in the specimen. The usual method consists of partial immersion, with alternate periods of immersion and drying. Sunlight or other sources of short-wave light should be used during the drying periods.

The accelerated test is made with solutions of hydrogen peroxide or sodium hydroxide with or without heat. Such tests are lacking in the elements of age and sunlight and are not conclusive.

The corrosive-atmosphere test is self-descriptive. The corrosive agents will vary with the purpose of the test, in some cases being heat and humidity, in others salt atmosphere and in other cases gasoline or fumes or similar corrosive agents from which protection is desired. The application of loads and stresses to specimens while they are undergoing corrosion tests is de-

sirable where such conditions are to be encountered in service. As previously mentioned, direct and flexural stresses may substantially increase the rate of corrosion. Recently we have been conducting a form of accelerated test by applying an external voltage to corrosion samples to bring out rapidly any inherent tendencies toward electrolytic corrosion that may exist. Our experience with this test is not yet general enough to warrant any conclusion as to its value.

By far the most conclusive and reliable laboratory test that we have been able to devise is one which was set up six years ago at Edgewater, N. J. By the joint action of the Aluminum Company and the Martin Company, apparatus and specimens were made and installed there on the top of an eight-story warehouse. The samples were 10 x 10 x 15-in. boxes representing typical assemblies that are common to metal airplanes. Duralumin channels, tubes and castings; galvanized, tinned and plain steel parts; wood inserts; brass and steel screws; fabric coverings and rubber handhole covers are included. The samples are set in a wood tank 2 ft. deep, 4 ft. wide and 15 ft. long, the test boxes being mounted with the open face downward. This tank is automatically flooded and drained once each hour with sea water drawn from the Hudson River, and the flooding operation completely submerges the specimens. The drain outlet is arranged so that the water level never falls below the bottom of the sample boxes, thus maintaining inside the boxes a moist chamber that is unventilated except for a small vent.

This test apparatus has been running continuously for six years with the exception of a few months each winter when freezing temperatures stop it. The apparatus is outdoors, and all samples are exposed to the weather, with direct sunlight on them. This test parallels very closely the conditions of service and in many instances in the last six years the results from the Edgewater tests have been checked against results in service and found to correspond very accurately. Many comparative data on corrosion-prevention methods have been accumulated, and this background is valuable when working out new methods.

THE DISCUSSION

C. H. SCHILDHAUER[8]:—The method used by Dornier in Germany and also by the licensee in Holland, the Aviolanda, is very different from what we are using here. The Aviolanda type of craft has been sent to Java, where it has the tropics to contend with, and Dornier has several craft in South America as well as in the Mediterranean.

Very little attempt is made to prepare the metal to resist corrosion. Dr. Dornier himself does not believe that the anodic method is the right way to combat corrosion, and in his ships very little actual work is done in combating corrosion through the anodic treatment or through bituminous paint. All heat-treatment is eliminated, the metal being used as it comes to the mill, and the various sections are drawn through a set of rolls instead of through dies under tension. How far he can go with that method of corrosion prevention remains to be seen.

LESSITER C. MILBURN:—Metal obtainable in this Country probably is more proof against corrosion when it is heat-treated. I am sure if we left it un-heat-treated we should have more corrosion trouble than we do.

CONRAD F. NAGEL, JR.[9]:—By virtue of the fact that the Martin Company has been engaged almost entirely in building Navy seaplanes, it certainly has been thrown into the thick of this problem, as I know of no service that is more severe. The paper correctly describes what is necessary to produce successful ships of long life, as is very well evidenced by the way the Martin ships are behaving.

Heat-Treatment Controls Corrosion

Intercrystalline corrosion and embrittlement occur only in the heat-treatable alloys. We never find it in non-heat-treatable aluminum or aluminum alloys. Whether an aluminum alloy such as duralumin will corrode by the intercrystalline method is dependent on the heat-treatment. With proper heat-treatment duralumin can be produced in the laboratory that cannot be made to corrode in this way, and the great majority of the material turned out today will not so corrode. However, our practices are not as yet so correctly adjusted that we can say that 100 per cent of the material is free from this tendency, but in general it is much superior to what has been put out in the past and we have every hope that before long we shall be able to make the statement that duralumin, as produced, is not subject to intercrystalline embrittlement.

The rivet corrosion mentioned is not explainable by service conditions but was due to a difference in the heat-treatment of the rivets. That has definitely been found to be the case in every instance where we have taken samples. It may be a matter of faulty heating or quenching. That is aside from whether the rivet has even been put through the heat-treating operation. Fig. 6 illustrates a case where the rivets were definitely in the annealed state. We can positively determine that by microscopic examination.

We have made an extensive survey of various manufacturing plants in the last two years, observing particularly this rivet situation, and have been rather surprised at the findings. The management and the foremen generally understand technical facts correctly. They know that they should heat to a proper temperature and quench quickly, but I was surprised to learn that in many cases the practices actually employed were very different from what was intended. Quenching is very important. The rivets must not be allowed to cool slowly between removal from the furnace and plunging in the water.

In one particular plant having a small electric furnace, each operator heat-treated his own little batch of rivets by putting them in a little can which he then placed in the furnace. In the meantime some other operator would put his can of rivets on top of the first can. The first operator would remove the upper can, stand it on the cold concrete floor, get his own can out and stand that on a cold concrete floor while he put back the second can. He then took his can of rivets,

[8] M.S.A.E.—Dornier Co. of America, New York City.
[9] Technical director, United States Aluminum Co., Cleveland.

dumped them into the water and thought that he had quenched them quickly. Actually, those rivets cooled appreciably while standing on the cold floor, and when I examined them they definitely showed inferior corrosion-resistance. The answer to the problem is that the management should have the operations supervised and actually obtain in their plants the conditions that they think exist.

I also want to endorse Lieutenant Schildhauer's remarks about doing more of the work with the heat-treated and aged material, and the aircraft manufacturers doing less heat-treating themselves. I think most aircraft manufacturers do not realize how much forming can be done on the fully heat-treated material. Those of you who have seen the U.S.S. Akron know the amount of forming that was done on the material in that structure. That material is what we term 17*SRT*. This is 17*ST* aged with some further cold rolling after heat-treating. The workability is somewhat less than with normal duralumin, 17*ST*, yet all this forming was done at the Goodyear plant without any heat-treatment there and with very few forming difficulties. The sheet manufacturer generally is in a position to heat-treat more accurately than will probably happen in the average aircraft plant. I do not mean to imply that all aircraft plants are not heat-treating properly or that they cannot. Most plants are heat-treating properly, but, if the sheet manufacturer will do this, we shall have an added assurance of best results.

Proper Preparation of Metal Necessary for Paint Adherence

We have done considerable work in connection with the Martin Company on the matter of protection against corrosion and are very firm believers in the necessity, first, of properly heat-treating and, second, of properly preparing the metal for painting. Good paint-adherence is essential, and the best paint will come off if the metal is not properly prepared. That is well illustrated if specimens of the same alloy are prepared in different ways—benzol cleaning, oxide coating or anodic treatment—and then each panel is painted in the same manner. If these specimens are then submerged in water for a long time, we shall find that the paint on the benzol-cleaned material will develop rather large blisters. Each blister is under pressure like a little rubber balloon and, if pricked with a pin, water will spurt out. A definite pressure exists tending to strip off the paint. Formation of gas in a blister is the result of action between the water and the metal. With good paint adherence those blisters will never be large, because the adherence of the paint film to the metal will be stronger than the strength of the paint film, and the latter will then break and only a small portion of the metal will be exposed. Otherwise before long the entire piece of metal would be exposed.

The anodic-treatment coating offers in itself considerable protection against corrosion and also is an absorbent film. The wet paint tends to soak into the film, thus providing very good adherence. The net result is that, when water penetrates through the paint, it first meets this inert oxide-film and no action tending to form gas and strip off the paint is started. The excellent results obtainable from the anodic coating have been amply demonstrated both in actual service and in many laboratory tests.

Again I want to stress proper preparation of metal for painting. I have been through the Dornier ship at the Naval Aircraft Factory very thoroughly and my reaction on looking at that ship was that so much paint was being applied that the result secured has been obtained by the volume of paint. I discussed the problem of protection with Dr. Dornier about a year and a half or two years ago and his comment was that he thought we were correct and had made far greater progress on this problem in this Country than they had. Probably the answer to Lieutenant Schildhauer's question is that our service conditions might be worse than those he mentioned.

Alclad Steel in Service

Mr. Milburn mentioned some corrosion of the Alclad 17*ST* sheet in the T4M floats that were built in 1928. A few months ago we took samples from the most affected portions of those floats and examined them to see how much of the aluminum coating had been removed. In no instance could we find that the coating had been removed to the core metal, not even in an area as large as a pin point. Tensile-strength specimens taken from unaffected and from the worst-affected areas showed no loss in the mechanical properties. That, of course, was to be expected if only the pure-aluminum coating had been affected and not the core. Mechanically, that float was still in perfectly sound condition.

On every possible occasion other instances of Alclad structures that have been in service and returned to us have been examined. An Alclad float was sent back by the Andean Airways after 19 months' service. One end of that line was on the Caribbean seacoast of Colombia and the other was up the Magdalena River in fresh water. The fresh-water end had no housing facilities, but the seacoast end did have. Upon examining the float, we again found absolutely no loss in mechanical properties in any portion of the Alclad 17*ST* structure nor any corrosion of the core. In that instance we found several areas where the pure aluminum had been removed down to the core, but no corrosion of the core, no intercrystalline corrosion and no embrittlement whatsoever had occurred.

Sections from several all-metal jobs have been examined by taking samples from the light-gage material, Alclad 17*ST*, of the wing covering. We have had complaints stating that the metal was corroding because an etching effect was seen on the surface. We have taken samples of such material and again have never yet found actual mechanical deterioration but simply a little surface etching.

Samples from the ZMC-2, the metal-clad dirigible that has now been in commission a little over a year and a half, have been examined by the Aircraft Development Corp. which built the ship, the Bureau of Standards and ourselves. This is very thin material, 0.0095 in. thick, and is used bare with no protection. When the material was made in 1927 we guaranteed a minimum tensile-strength of 50,000 lb. per sq. in. After service, the tensile strength was between 56,000 and 58,000 lb. per sq. in. We guaranteed a yield-point of 27,000 lb. per sq. in. although the material will average a little over 30,000 lb. After service, we found values of 36,500 and 37,500 lb. per sq. in. The guaranteed elongation was 16 per cent; the average value was 18.5. No loss was noted. These results check well with the values found by the Bureau of Standards and by the Aircraft Development Corp.

The real problem of corrosion prevention rests with

the aircraft manufacturer, and, as has been pointed out, it starts right with the designer. I was glad to hear Lieutenant Schildhauer state that the Dornier people pay so much attention to this subject. Designers in this Country could well afford to pay more attention to it. I wonder how many designers know anything about the corrosion problem; how many of them take it into consideration at all in their design. In numerous instances the material is used in such a way as to provide cups to hold water; for example, channels turned up rather than down, where the section could be turned around just as easily so that it would drain. I realize that this cannot be done in every case, but too frequently the matter has not received sufficient consideration.

CHAIRMAN EDWARD P. WARNER[10]:—I do not know that everybody understands just what is meant by the statement that no heat-treated material or no heat-treatment of material was used in the Dornier boats. I know it was not clear to me at first. Mr. Nagel's understanding is, I believe, that the material was preheated or received from the factory in the heat-treated condition, not that it was used in a non-heat-treated state. Is that correct?

MR. SCHILDHAUER:—Yes.

S. E. LEA[11]:—One point of information that might be of more interest to the service operator than to the constructor has to do with the possibility of the correct use of rivets in the field. In fact, because of lack of this information, I have been forced to make repairs to all-metal seaplanes with the use of non-heat-treated duralumin rivets or ordinary aluminum rivets, with very unsatisfactory results.

If used judiciously, a plumber's vertical gasoline torch and lead pot, plus a solution of sodium and potassium nitrates in equal proportion at a temperature between 940 and 960 deg. fahr. and, most important of all, a thermometer with a range of 1000 deg. fahr. supplied by the Taylor Instrument Co. is all the equipment that is absolutely required to attain the very critical heat-point necessary for proper heat-treating of duralumin rivets.

Mr. Milburn mentioned that rivets could be heat-treated an indefinite number of times. As this is contrary to the practice in our plant, where we throw out rivets that show dark discolorations, I wonder if we are on the wrong track.

MR. MILBURN:—As far as we have been able to determine, if each heat-treatment cycle is accurate, how many times the rivet is heat-treated does not make any difference.

MR. NAGEL:—We have heat-treated a coil of wire, cut off a sample and re-heat-treated the remainder, repeating that more than 20 times, and have then determined the mechanical properties of each sample. We found no change of any magnitude.

Will Stainless Steel Replace Duralumin?

I. SIKORSKY[12]:—Duralumin is known to possess certain limitations in connection with the corrosion problem. At present we hear considerable about stainless steel, which apparently solves all of these problems. However, some other problems and difficulties, which we do not yet know about, may later arise in connection with stainless steel. I believe that duralumin is here to stay in aviation, but I would like to hear whether these limitations will finally bring about the replacement of duralumin by stainless steel.

MR. MILBURN:—Making any airplane entirely of one material, such as stainless steel or anti-corrosive steel, is impossible, and therefore we are bound to have dissimilar metals in any airplane. As long as we have dissimilar metals in sea water, we shall have corrosion.

B. V. KORVIN-KROUKOVSKY[13]:—Can Mr. Nagel give us some comments on the possibility of using some other modified rivets that could be used in connection with the Alclad and would not be heat-treated at the factory?

MR. NAGEL:—We have several grades of the 17*S* alloy. We can dilute 17*S* by using a smaller quantity of the hardening constituents. This makes possible upsetting or pointing pre-heat-treated and pre-aged rivets in the field. We call these compositions, which are different from the 17*S* and contain less copper and magnesium and no manganese, *B*17*ST* and *A*17*ST*. Because of composition differences the *B*17*ST* in conjunction with 17*ST* would set up an electrolytic couple, hence we would not advocate the use of *B*17*ST* for the bottom of a boat hull, seaplane float or similar purposes. In Alclad 17*ST* sheet, however, this composition would be protected by the pure-aluminum coating in the same way that the 17*ST* rivet is protected. To determine the degree of protection afforded by the pure aluminum, we drilled discs on the surface, varying from ⅛ to 1½ in. in diameter, just deep enough to remove completely the pure-aluminum coating from the surface of some Alclad 17*ST*. The specimen was then subjected to corrosive influences by immersion, and later the exposed core was examined. We found that even in the largest disc the exposed core in the very center was still perfectly free from corrosion, which, of course, should happen according to fundamental principles. Therefore I would say that the use of *B*17*ST* rivets in Alclad sheets is one answer to the question.

Zinc as a Corrosion Preventive

N. J. DEN TEX[14]:—In shipbuilding, a zinc plate is very often used to remove the possibility of corrosion, especially if bronze and steel are in fairly close proximity under water. Could any other metal or material be used in the flying-boat hulls or pontoons to take the place of the zinc plates and perhaps give the same results and protect the different materials that are in contact with the water?

MR. MILBURN:—None of which I know. I wish that a metal which would be consumed and thus protect the alloy might be developed. The nearest approach is the Alclad sheet, which, as Mr. Nagel explained, is good for at least two years. The Aluminum Co. of America may have something in prospect which has not been divulged, but so far as I know no metal that could be used exists.

MR. NAGEL:—Magnesium is the only common metal known which will work in that direction. It is on the other side of aluminum in the electrochemical series. The potential between magnesium and aluminum is in favor of the latter, but as yet such a use of magnesium is not practical.

R. M. MOCK[15]:—I have heard that experiments have

[10] M.S.A.E.—Editor, *Aviation*, New York City.

[11] A.S.A.E.—Aircraft mechanic, Keystone Aircraft Corp., Bristol, Pa.

[12] M.S.A.E.—Vice-president in charge of engineering, Sikorsky Aviation Corp., Bridgeport, Conn.

[13] M.S.A.E.—Chief engineer, Edo Aircraft Corp., College Point, N. Y.

[14] M.S.A.E.—Chief sales engineer, Oertz Streamline Rudder Corp., New York City.

[15] Jun. S.A.E.—Consulting engineer on design and production, Ernst Heinkel Flugzeugwerke, Warnemunde, Germany.

been conducted in Russia, I do not know how authentic my information is, of putting zinc plates on duralumin structures. Some of the metal airplanes have zinc plates that are attached every night when the machine goes into the hangar. In certain places and, of course, according to Table 1, the electrolytic action should work that way. The airplane is also electrolytically grounded when it is not in service. Incidentally, I have heard that duralumin protected with zinc chromate gives excellent results. This is standard practice with some manufacturers.

MR. NAGEL:—We have found instances where the potential current went in the direction favorable to aluminum. This was in testing 17*S* and nothing else. We do not know why this occurs and apparently the current does not always flow in a favorable direction.

CHAIRMAN WARNER:—You have found cases in which the attachment of zinc plates would be beneficial?

MR. NAGEL:—This was just a laboratory test in which the potential measured was found to be favorable to the aluminum-alloy side, which means that the metal in the direction in which the current of the circuit flows is protected.

CHAIRMAN WARNER:—You said previously that magnesium was the only material available for that purpose in conjunction with aluminum and that to use it was not practical. Why is that?

MR. NAGEL:—Magnesium is attacked very rapidly by soft water. I do not think it would last very long in such an application.

EDWARD WALLACE[16]:—What is the relative comparison of the salt-water corrosion with the *SRT* and the *ST* alloys?

MR. NAGEL:—We have made extensive comparisons and found no difference. We have rolled 17*ST* with various reductions from 0 up to 50 per cent, the work being planned so that all the samples were of the same gage. We then subjected this material to severe corrosive conditions at the same time and ascertained the change in mechanical properties. We could not pick one sample from the other with respect to the loss in mechanical properties.

[16] M.S.A.E.—Consulting aeronautic engineer, Cleveland Heights, Ohio.

New Foreign Alloys

MR. MOCK:—Do you know anything about the new German alloy called Duralplat? It is coated with an alloy that is not chemically pure aluminum and is extensively used in Germany.

MR. NAGEL:—That particular term is new to me, although I know that experiments are being made with several alloys of that class. The Germans, I understand, are also putting out a sheet with some low-copper alloy coating with which we have also worked. The underlying principle is that the difference of the potential between pure aluminum and a copper alloy becomes less as the percentage of copper in the alloy decreases. In other words, the potential between a 2-per cent and a 4-per cent copper alloy would be less than between pure aluminum and a 4-per cent copper alloy. Therefore the actual attack on the coating would be slower if the low-copper alloy were used on the surface. However, we are not at all satisfied with such a material.

MR. MOCK:—I have been given to understand that the test conducted last winter at the D.V.L., the German aeronautical research laboratories, showed that Duralplat, which is made by Dürln, the German aluminum company, was the best corrosion resistant of any tested. I believe they claimed that it was a little better than Alclad. I do not know how authentic those tests were or whether the materials were subjected to all kinds of conditions.

Wind Resistance of Motor-Cars

THE EFFECT of wind resistance is illustrated by figures, all of them approximate, regarding the performance of the Studebaker President car. The 125-hp. engine of this car gives the sedan model a top speed of 80 m.p.h. If a 200-hp. engine should be substituted, with no other change in the chassis or body, the top speed would be increased to 93½ or 94 m.p.h. This illustrates how little gain can be made in the top speed of a fast automobile by making any reasonable increase in the power of the engine.

Substituting on the same chassis, with the original 125-hp. engine, a streamlined roadster body which is designed for low wind resistance, the car will make a top speed of 107 or 108 m.p.h. This indicates the gain in high-speed performance that is possible with streamlining.—From an Indiana Section Meeting paper by D. G. Roos, chief engineer of the Studebaker Corp. of America.

Spring-Shackles

NO GREAT change has occurred in the proportions of spring-shackles of the various sorts in the 1931 cars. Rubber shackles are found on 30 chassis models, 13 of them being of the block type, 10 rubber bushings, 3 of the rubber-fabric type and 4 of miscellaneous bushed types. Self-adjusting metal shackles of a single make are found on 24 chassis, 4 have ball-bearing shackles and the remaining 24 models are fitted with conventional metal shackles.—From an Indiana Section Meeting paper by D. G. Roos, chief engineer of the Studebaker Corp. of America.

The Place of Industrial Trucks in Automotive Materials Handling

Milwaukee Production Meeting Paper

By C. B. Crockett[1]

MATERIALS handling is a by-product of low-cost mass-production methods, and it is in the smooth, fast movement of raw materials and semi-finished parts that the automotive industry has achieved outstanding success and realized astounding economies. It has even been said that in the planning of an automotive plant the actual production operations performed are secondary in importance to the problem of how the materials will flow from one operation to the next. This probably is a mild exaggeration of the attitude of the management of automotive plants toward materials handling, but the interest and study given by management to this problem have served to accentuate the complications that exist and to drive home forcefully the fact that materials handling is not, and never can be, an exact engineering science. This is because of the total lack of any common scientific terminology and because every problem is a combination of factors that is seldom, if ever, exactly duplicated in another plant.

To treat of the place of electric industrial trucks in the general handling system, we must make certain more or less arbitrary classifications of handling problems before discussing the requirements of these problems and the characteristics of the different types of equipment that may meet these requirements. Actual examples are chosen in preference to generalization, as the lack of uniformity among various plants in material-handling requirements makes generalization meaningless and easily misinterpreted.

The author points out the many variable factors entering into any materials-handling problem and the difficulties incurred in selecting the equipment that will result in the lowest over-all cost during a period of years. He discusses briefly the proper fields for all types of mechanical equipment to indicate more clearly that in which the power truck has been most advantageously applied. Recent applications of this type of equipment are described and examples of costs and savings are given.

Constant-Flow and Periodic Handling

Handling problems fall into two general classifications. The first is the handling on the actual production-line. Here a uniform material moves constantly between two fixed points at a rate set by the speed of the production operations at the two ends of the movement. Although under certain conditions an opportunity exists for providing a cushion stock between operations, the rate of discharge of the first machine over a short period of time is equalled by the rate of consumption at the other end of the handling operation. Therefore the conditions are ideal for conveyor equipment of all kinds; namely, a uniform flow of uniform material, in small units but large total quantity, moving always along the same fixed route.

No clearly defined dividing line exists between this class of handling operation and the second general class, which is characterized by periodic movement of materials not always uniform nor for the same destination. Let us take for example the movement of steel sheet from box cars to storage or start of process. Over a fairly long period the consumption of sheet is equal to the quantity delivered, but the economic rate of unloading a car of sheet of a certain size will not be the rate at which that size is consumed. This is the elemental characteristic that determines the choice of one or another type of equipment. Sheet of widely varying size and weight must be handled by the same equipment. Further, a car of steel cannot always be spotted in the same position for unloading, and the material may have to be delivered to any one of a number of machines or to storage. Therefore we have a material that is not uniform as to size, weight, destination or rate of movement. This is a typical example of periodic movement as differentiated from continuous-flow movement.

Operations Classified

With this differentiation in mind, let us examine the principal handling operations in any manufacturing plant. These may be roughly classified as movement of

(1) Raw materials from common carrier to storage or process
(2) Materials from storage to process
(3) Materials through process and assembly
(4) Finished product from production to storage or shipment
(5) Finished product from storage to shipment
(6) Supplies, machines and machine parts to and from place of use.

General operation (3) of moving materials or semi-finished parts through production and assembly probably will embrace many more separate handling op-

[1] Secretary, Industrial Truck Association, New York City.

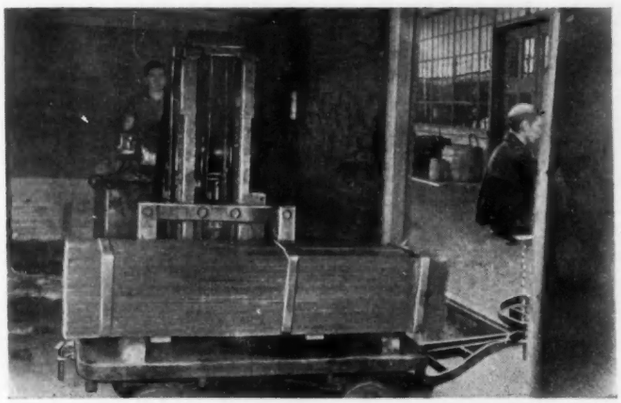

FIG. 1—REMOVING BUNDLES OF SHEET STEEL WEIGHING 8000 LB. EACH FROM BOX CAR WITH FORK-TYPE ELECTRIC TRUCK

erations than the combined totals of all the other listings, but these handlings may be grouped, as they are typical of continuous-flow operations and, although of outstanding importance, they should not be considered to the exclusion of the handling of raw materials and finished product and other handlings of a periodic nature. Operations (1), (5) and (6) are distinctly of the periodic type; operations (2) and (4) may be either periodic or continuous, depending upon the conditions of the individual case.

Conveyors of all types are without doubt the most economical mechanical equipment for use where the continuous flow of materials is sufficient to warrant a comparatively high capital investment and the chances of a change in the operation are not likely within the period required to pay off the investment. If the quantities moved are smaller than are required to make the installation of conveyor equipment economical, a periodic method of movement may be adopted.

The essential principle of periodic movement, for which the power truck is admirably suited, is the increase of size of the unit load moved and the elimination of individual handlings at the beginning and end of the production operation. Both overhead cranes and power trucks satisfy these conditions. The crane can handle larger and heavier loads than the truck and with a possible saving of floor area, but building construction may preclude the possibility of crane service and, as previously mentioned, these periodic movements often vary widely as to area served or destination of material, which conditions are conducive to the employment of the mobile type of equipment.

New Methods of Handling Sheet Steel

A typical illustration of the use of electric trucks is found in the handling of sheet steel. Fig. 1 shows in the background a machine for handling bundled sheet in packages up to 8000 lb. in weight and 96 in. in length. The bundles are placed crosswise in the railroad car upon dunnage strips which permit the insertion of the forks of the lift under the load. The load is so spaced in the car that the truck can pick up the front bundle and then back up far enough so that the load is exactly opposite the car door. The truck has raised the bundle high enough for a trailer to be inserted under the forks, and the trailer, when loaded, is drawn from the car without any maneuvering by a tractor, which hauls it 300 ft. to storage.

This is an excellent example of the coordinated use of different types of mobile equipment to secure the highest over-all efficiency. The lift-truck continues to shuttle from end of car to door until one-half the car is unloaded; it is then run out of the car, turned around and re-enters facing the opposite way to unload the other half of the car. Upon completion of the unloading operation, the truck is moved to the storage area shown in Fig. 2 and unloads the trailers, stacking the steel two to four bundles high. This system has cut the cost of unloading sheet steel in a large automotive plant from 14 to 2 cents per ton, and the labor saving the first year amounted to more than $80,000.

A similar operation for larger sheets is accomplished by means of a special truck shown in Figs. 3 and 4. In this case, sheet steel up to 120 x 48 in. is bundled in packages weighing as much as 20,000 lb., with 2 x 4 or 4 x 4-in. lumber wired to the sheet as an integral part of the bundle. The truck platform is tilted and cables from a motor-driven winch are passed around the bundle. Winding up of the cable provides a lifting and pulling action that draws the load up on the platform, which is then lowered to a horizontal position. In unloading, the process is reversed, the platform being tilted and the cable paid out as the machine is withdrawn from under the load. The truck platform and driving unit are connected by means of an artificial joint that enables the maneuvering of the machine in very congested areas. A 40-ton car of sheet steel has been loaded with this machine in 25 min. by two men.

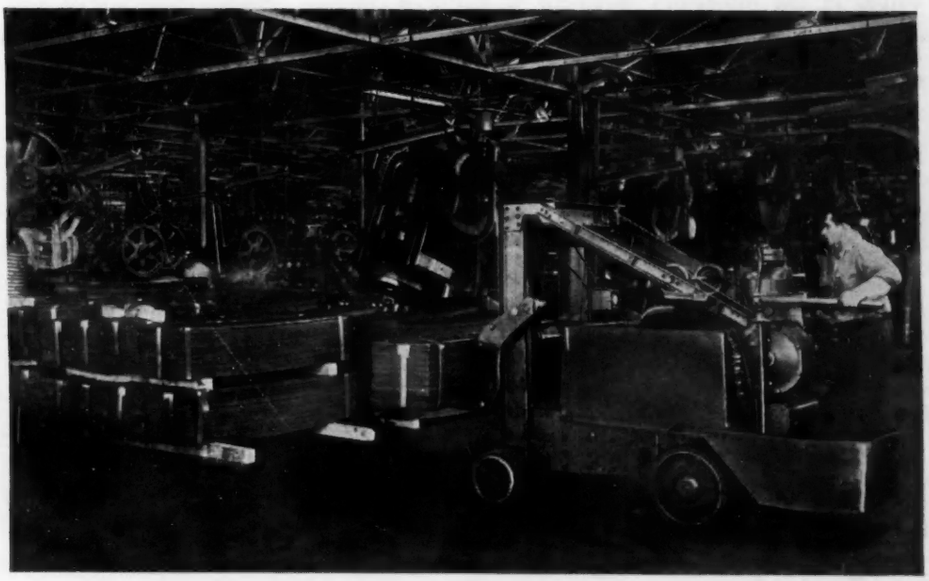

FIG. 2—STACKING BUNDLED SHEET STEEL AT START OF STAMPING OPERATION

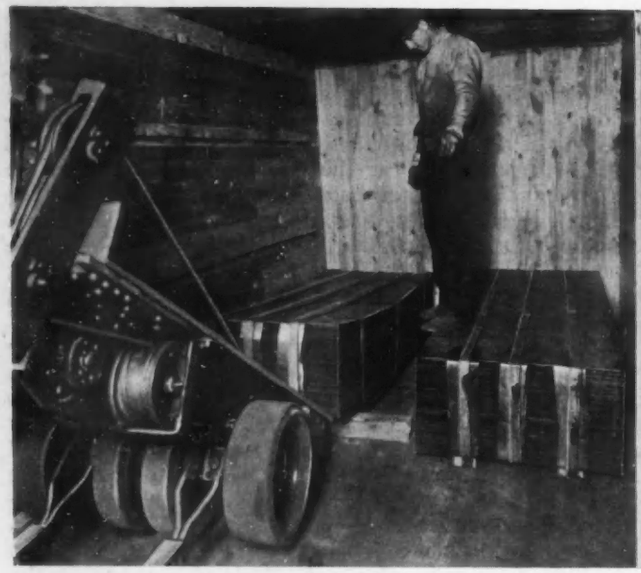

FIG. 3—UNLOADING 10-TON BUNDLES OF STEEL FROM BOX CAR WITH TILTING-PLATFORM TRUCK

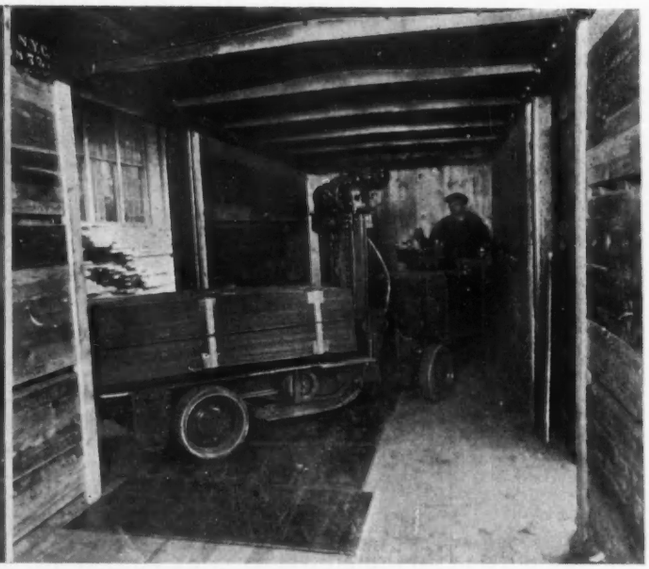

FIG. 4—ARTICULATED TRUCK LEAVING BOX CAR WITH LOAD OF SHEET STEEL

The foregoing are typical examples of periodic handling in which the size of the unit handled has been increased with a corresponding decrease in handling cost and a reduction of damage to the product and possible injury to workmen to the absolute minimum. The fork type of machine is also being used successfully for rod and bar stock and for small shapes that can be bundled by the manufacturer. The tilting type of truck is available for handling any very heavy material that comes in large units and cannot conveniently be placed on skid platforms.

Skid Shipment Growing Rapidly in Practice

The automotive industry has taken a leading part in extending the production line and its efficient method beyond the doors of the plant. Due attention has been given to the way in which material is shipped by the suppliers of parts, and in several instances has resulted in the interplant shipment of material on skid platforms either by rail or by motor-truck. Here again the reduction of individual rehandling and the lessening of handling damage have resulted in great economies.

We are fortunate in having complete figures on the shipment of brakes by the Bendix Brake Co. Under the former method, brakes were placed in trays from storage, wheeled to freight car and loaded in tiers, the maximum possible height being 12 trays. This made possible the shipping of 2400 brakes per car. The total cost for labor, lumber and bracing was $126.50 per car, or $0.053 per brake. The new method is to place the brakes in built-up skids at the completion of inspection, as shown in Fig. 5. These are moved directly to cars by an electric lift-truck, each skid containing 240 drums. Eight skids are placed in each end of the car and steel strapping placed in the car prior to loading is fastened around the entire load.

The 16 crates are loaded by one man and the electric truck in approximately 25 min., and the work of two men is required for 45 min. to place the strapping in the car and secure the skids after loading. The labor costs for loading are as follows:

1 truck and driver, ½ hr.	$0.75
2 men, ¾ hr.	0.75
	$1.50

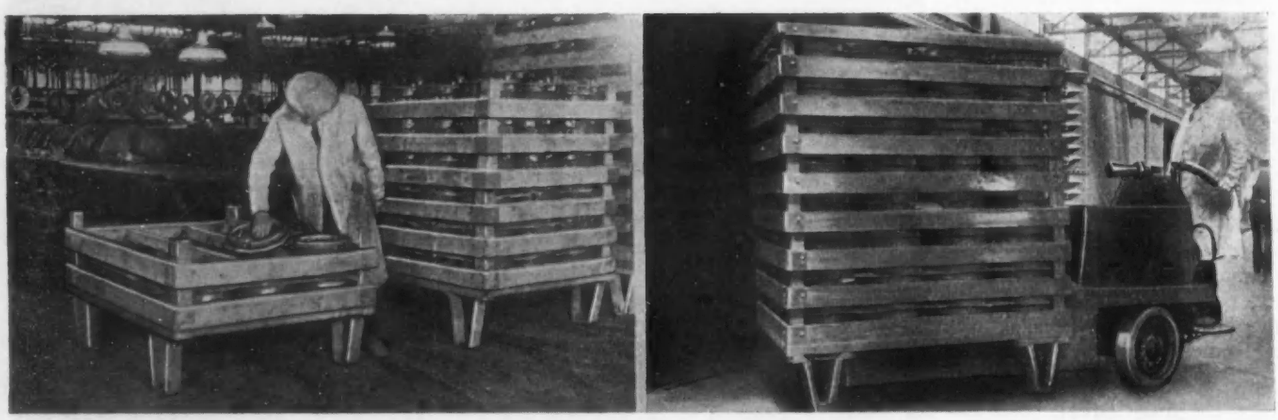

FIG. 5—LOADING BRAKES INTO SKID RACKS AT COMPLETION OF ASSEMBLY OPERATION, AND (RIGHT) TRUCKING SKID RACKS CONTAINING 240 BRAKES INTO BOX CAR

To this must be added the cost of the skids and that of their back haul to the plant. Skid racks cost about $40 each, or $640 per car. At the time of installation, each skid was estimated to be good for 60 trips, and this figure is still used for cost purposes although the older skids have made more than 90 trips. Thus the cost per carload shipped with skids is $640 divided by 60, or $10.66. Return skids from three loaded cars come back in a single car, taking fifth-class rate (24,000 lb. minimum) as an exception of Official Classification. The cost of back haul is therefore approximately $20 per car for an average haul of 300 to 400 miles. Following is a summary of costs:

	Tray Method	Skid-Rack Method
Brakes per car	2,400	3,840
Total packing and loading cost, per car	$126.50	$32.16
Cost per brake	$0.053	$0.008
Saving, per cent		85
Damage in transit, per cent	2	0

The management at South Bend, Ind., has stated that it would use the skid method even if it cost more than the old method, as the use of skids reduces the handling operations from brake-assembly line to automobile-assembly line from six to one, as follows:

Brake Plant

Old Method	New Method
Line to Platform	
Platform Taken to Car	Line to Skid Racks
Platform to Rack	

Automobile Plant

Car to Truck	
Truck to Stockroom	Skid Racks to Assembly Line
Stockroom to Line	

FIG. 6—MOVING AUTOMOBILE BODIES ON END WITH SPECIAL-TYPE ELECTRIC TRUCK

In addition to the foregoing advantages, only one type of brake is placed in each skid and, by means of different colors, the skids are used as automatic inventory units, which simplifies the packing count.

More and more concerns are adopting this method of interplant shipment, particularly where the movement is by motor-truck between plants of the same company,

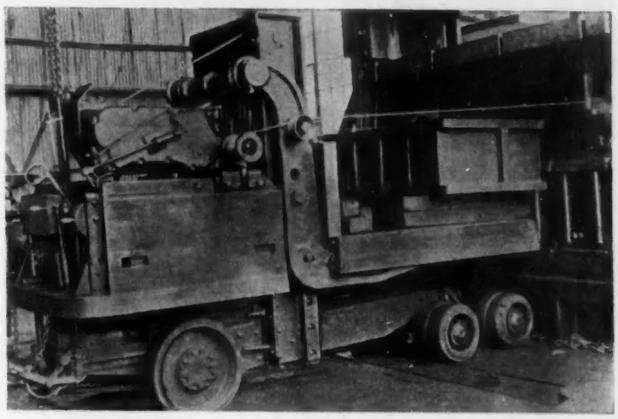

FIG. 7—REMOVAL OF 17½-TON DIE FROM PRESS BY ELECTRIC TRUCK WITH WINCH ATTACHMENT

but the economic possibilities of this system have not been realized to anywhere near the possible extent in the movement by freight of automotive parts from supplier to car manufacturer. The problem of the return of skids continues to be a bugaboo, although the Bendix company believes this method would prove economical up to a distance of approximately 700 to 900 miles.

Advantages of New Body-Handling System

The use of electric trucks in handling finished product is restricted largely to manufacturers of automotive parts, but automobile bodies may be regarded as a finished product even where placed on the chassis at the same plant. The outstanding example of their use for this purpose is in the plant of the Studebaker Corp. at South Bend, where, by means of a special truck, bodies are moved as shown in Fig. 6 and stored on end. This has resulted in

TABLE 1—COST COMPARISON OF DIE-HANDLING METHODS

	Old Method		New Method	
	Minimum	Maximum	Minimum	Maximum
Men Required	9	12	2	2
Time for One Change, hr.	1½	2	1/3	1/2
Number of Changes per Day	10	20	10	20
Total Press Time Lost, hr.	15	40	3⅓	10
Saving in Press Time, hr.			11⅓	30
Labor Cost at 55 Cents per Hr.	$74	$264		
Labor Cost at 55 Cents per Hr. and Truck Cost at 75 Cents per Hr.			$9.25	$12.37
Saving per Day			$65.75	$251.63

(1) The storing of 1900 bodies in the area formerly occupied by 750 and the saving of an investment of $125,000 in additional storage space

(2) A 46-per cent reduction in labor cost of handling in the body-storage department

(3) The elimination of 90 per cent of the handling

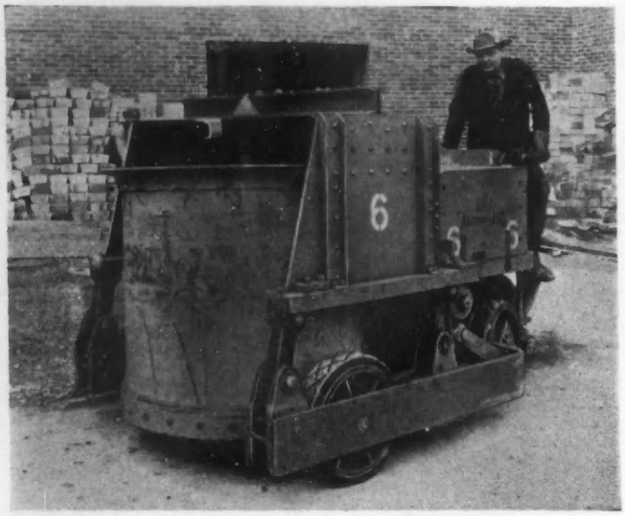

FIG. 8—SPECIAL MACHINE FOR HANDLING CUPOLA CHARGING BUCKETS IN COMBINATION WITH WHITING CRANE

damage, which formerly amounted to $500 to $600 per month

(4) Greatly increased flexibility and coordination with the assembly line, as bodies of any style or color are instantly available, with the minimum of rearrangement necessary.

Moving Machine Equipment

All the operations described have been connected with the handling of the product in the form of raw materials, semi-finished or finished parts. While this class of handling is of prime importance, attention is sometimes concentrated upon it to an extent which results in the neglect of another class which might be called "service to production." This handling must be periodic, and, although the amount of handling is seldom large enough to make any direct savings of great import, the indirect effect of the handling method in speeding up production operations makes it worthy of careful consideration.

There is no better example of this class of handling than that involved in the movement of dies in and out of presses and storage. Although in larger plants the labor costs of this operation may amount to a considerable figure, the essential factor is the number of non-productive hours of the presses and their skilled operators. Table 1 shows savings for die changes before and after the introduction of high-capacity (30,000-lb.) die-handling trucks in a large automotive plant (See Fig. 7). The direct savings are large, but the indirect savings in the productive capacity of the presses is further supplemented in other fields where it is impossible to secure accurate figures. First, the possibility of serious injury, which was ever present under the old method, has been eliminated; second, dies can now be removed to a suitable storage area at some distance from the presses, which has released an area in the press room equal to one-half the former productive area; and, third, it is now economical to put through a more varied schedule by changing dies more often, thus reducing cushion stocks and maintaining closer control of inventory.

FIG. 9—SPECIAL RACK FOR HANDLING FRONT-AXLE ASSEMBLIES

Flexibility of System Is an Advantage

Business conditions today have taught two great lessons: first, plants, and their handling systems as part of the plants, must operate economically, if possible, on a low-production as well as a high-production rate; second, to keep pace with competition, the management of any plant must be in a position to change its design, and perhaps its processes, to meet new demands of customers or take advantage of new processes and methods. Flexibility is a paramount advantage if it can be maintained at low cost; and flexibility in handling methods is secured through the use of mobile equipment. This should not be interpreted as a recommendation of such equipment for operations in which fixed types of equipment will yield from 50 to 200 per cent return on the investment yearly; but, in cases where the return from mobile equipment is close to that of a conveyor, the item of adaptability to varying production schedules and new processes or to rearrangement of machines should be given consideration.

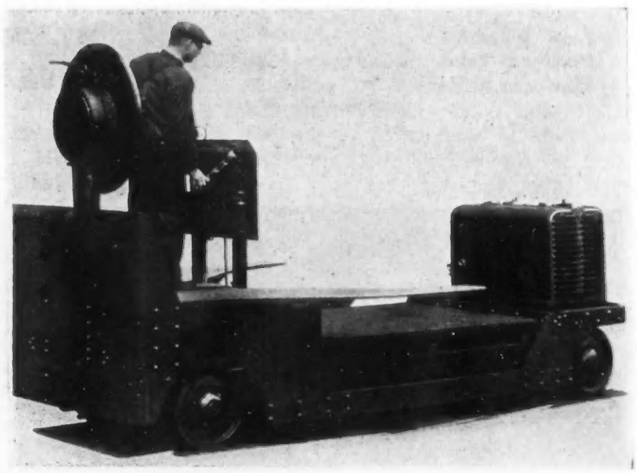

FIG. 10—NEW ELECTRIC TRUCK FOR WEIGHING AND TRANSPORTING CUPOLA CHARGES

The automotive industry has been a pioneer in the development of economical mechanical handling (See

Figs. 8 and 9). Fig. 10 shows a new machine for weighing and transporting cupola charges at one of the Ford plants. The center portion of the machine forms a platform scale, the weight of the charge being registered on the dial directly behind the driver. The centralization of authority for this service is also common in many plants. It is not so common, however, to find the application of wage-incentive plans to this type of work. In the use of mobile equipment a distinct human factor exists, and due attention to the personal equation is productive of remarkable results. The Norton Co., of Worcester, Mass., introduced a simple bonus plan based on the number of loads handled per day per truck. The number of trips per day per man was stepped up from 30 to about 60; the labor cost per trip was cut from 14 to 8 cents, and the earnings per man increased 35 per cent. If the cost per ton moved can be made approximately equivalent, it is preferable to pay this cost in wages rather than in interest and depreciation charges, particularly where obsolescence may be an important and unknown variable.

Grateful acknowledgment for material in this paper is made to B. J. Sanford, transportation manager of the Bendix Brake Co.; John R. Sullivan, supervisor of transportation of the Studebaker Corp.; G. E. Phillips, of the gear and axle division of the Chevrolet Motor Car Co.; and B. A. Hildebrant, of the methods department of the Norton Co.

Streamlining Applied to Automobiles

(*Concluded from p.* 128)

B, 3900 lb. Therefore, the miles per gallon were: Car *A*, 22.5 miles; Car *B*, 13.8 miles. The saving in fuel of the Jaray-Chrysler car, compared with the standard Chrysler car, corrected for weight and so forth, was therefore about 40 per cent.

Theoretical Analysis of Power Required

According to the well-known formula, the tractive effort necessary for keeping the car at constant speed consists of the following components: the power necessary for overcoming the losses in the engine, the driving mechanism and rolling friction, that needed for overcoming the friction of the air, and the gravity component of the slope.

We can find the horsepower required for maintaining the car at a given speed by the equation

$$Hp = v/75\eta\,[(\mu \pm \sin\sigma)\,G + FC_d\,1/2\rho\,(v \pm w)^2] \quad (1)$$

where

C_d = coefficient of drag
F = projected front surface of the car in square meters
G = weight of the loaded car
v = velocity of the car, in miles per second
w = wind velocity, in miles per second
η = efficiency of the engine and driving mechanism
μ = drag
ρ = density of the atmosphere
σ = angle of slope of the road

Using in this formula the values for the drag as found in the wind-tunnel tests as well as in other tests, it will be seen that, during the road tests mentioned, the engine in Car *A* developed 14 hp. and that in Car *B*, 20 hp.

Comparing the power developed in the two cars, as stated, with the quantity of gasoline used; namely, 1.45 and 2.5 gal., respectively, it can be seen that the engine of the Jaray-Chrysler car was working at a far lower percentage of its normal rating than that of the standard car, and consequently at a much lower efficiency. Therefore, correcting for this lower efficiency, we would find that the saving of 40 per cent in fuel consumption would amount in reality to more than 45 per cent.

An idea of the savings that could be obtained in the horsepower capacity of the engine at various speeds for different cars is given by Table 2. These data were computed from equation (1), taking into account the coefficients found in the laboratory and in wind-tunnel tests. They show clearly that, even at moderate speeds, a great saving can be effected. Owing to the necessity for having to slow down and speed up the car when going around curves and through towns, an even greater saving is effected with the streamlined car than is actually proved in the road tests mentioned.

Looking at these results from a different angle, it can be seen that the application of the perfectly streamlined body to a car will make possible the use of a smaller engine and perhaps also a simpler transmission and a lighter chassis frame.

In addition to all the foregoing advantages derived from the use of the streamlined body, several other and quite outstanding advantages are obtained, as experienced during trial runs with the Jaray-Chrysler car. These include:

Ventilation.—There is no offensive back-draft at any speed, and the fresh air admitted can be regulated by means of a small opening.

Vibration.—As there are no obstacles to the passage of the air, whirls are minimized and also, in turn, the vibrations, whistles and other noises due to the wind.

Floor Space.—The floor space inside the car is increased and a great deal of space is available for trunks, spare tires and the like.

Safety.—Because of the rounder surface of the car, accidents are much less dangerous than with the present types of car.

Visibility.—The shape of the car, as shown in Fig. 4, permits of much better vision both vertically and horizontally. Moreover, rain drops are sucked off the windows and do not interfere with vision.

Automotive Research

Tentative Recommended Practice for Conducting Antiknock Tests

THIS tentative recommended procedure for conducting antiknock tests has been developed by the Detonation Subcommittee of the Cooperative Fuel-Research Steering Committee for the use of purchasers of the C. F. R. engine or of other interested persons. However, since the recommendation is based merely upon the best knowledge at the present time, it should be regarded only as a tentative method subject to frequent modification and change in accordance with future developments and further research work of the Committee.—[Ed.]

1.—Introduction

The following practice for determining octane numbers[1] of motor fuels is suggested for the purpose of obtaining uniformity in the industry. It represents one of several methods and has been selected because, in the light of our present knowledge and experience, it is the one which is most likely to give reproducible results. The equipment mentioned has been built especially for this purpose and is recommended as being the best available for the purpose at this time. It is recognized that, as our knowledge of the art increases, changes will necessarily be made in both equipment and technique, and therefore the following practice is subject to revision. The present practice should not be applied to aviation fuels, which will be treated as a separate subject at a later date.

2.—Apparatus

The apparatus to be used for determining octane numbers of motor fuels is composed of an engine, a method of loading, and control equipment to bring the apparatus to fixed operating conditions, together with suitable accessories to supply fuels under test to the engine and measure the resultant knock intensity.

The engine recommended is that developed especially for this purpose by the Cooperative Fuel-Research Steering Committee and manufactured by the Waukesha Motor Co., of Waukesha, Wis. References to "the engine" will be understood to mean the engine with variable compression-ratio and integral head which will be called "the C. F. R. Engine."

Loading and accessory equipment is furnished as a unit with the engine. This includes a cast-iron base on which is mounted the engine, the power-absorbing medium and the panel board. Essential control equipment, instrumentation, switches, and so forth, are suitably mounted. The carbureter was designed especially for this engine and may be ordered with either two or four float-bowls as desired.

The knock-measuring device is a bouncing-pin coupled with either a gas-evolution burette or a knockmeter, as preferred[2].

3.—Foundation

The foundation, if possible, should be poured on a concrete floor and should have a height of at least 18 in. Proper dimensions will be furnished with the engine. For convenience in operation, the foundation should be placed at least 2 ft. from any wall. Should the floor of the building in which an engine is to be installed be other than Portland cement, the floor should be cut away so that the engine foundation will rest directly on the ground. In such case the depth of foundation should be increased to give ample footing depending upon the condition of the underlying soil.

4.—Engine Control

Start the electric motor by means of the push-button switch. With the engine being turned over by the motor, turn on the ignition and set a carbureter cock so as to draw gasoline from one of the float-bowls. To stop the engine, turn off the fuel and ignition switch and stop the motor by means of the push-button switch.

5.—Standard Adjustments

(*a*) Engine Speed, 600 r.p.m.

(*b*) Jacket Temperature, boiling water

(*c*) Cooling Water, distilled or rain water

(*d*) Crankcase Oil, S.A.E. No. 20

(*e*) Valve Clearances, as recommended by manufacturers

(*f*) Spark Advance, maximum power (automatically adjusted)

(*g*) Breaker-Point Clearance, 0.018 to 0.022 in.

(*h*) Spark-Plug, as recommended by manufacturers[3]

(*i*) Spark-Plug Gap, 0.025 in.[3]

6.—Reference Fuels

The primary reference fuels to be used are those approved by the S. A. E. Standards Committee: iso-octane (2, 2, 4 tri-methyl pentane) and normal heptane. In view of the expense and limited supply of heptane and octane, it is expected that individual laboratories will use secondary reference fuels for routine determinations[4]. Such reference fuels may be straight-run or other stable gasolines suitable for the purpose. One of these should be of low antiknock value and the other of high antiknock value, or, if a sufficiently high antiknock fuel is not available, a mixture of the higher antiknock fuel plus a knock suppressor may be used. These reference fuels should be calibrated on the octane scale against heptane and octane sufficiently often to insure accuracy of calibration, and, for every case where a fuel is rated by secondary reference fuels or by means

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[1] Octane number is numerically the percentage by volume of iso-octane (2, 2, 4, tri-methyl pentane) in a mixture of iso-octane and normal heptane. The octane number of a fuel is the octane number of the mixture of iso-octane and normal heptane which it matches in antiknock value.

Note.—As it appears probable that future developments may result in fuels approaching pure octane in antiknock value, or even exceeding it, pure octane would have an octane number of 100 and the scale can be extended above this point by such a secondary definition as octane numbers above 100 are defined as 100 plus the percentage of pure benzene (C_6H_6) in iso-octane-benzene mixtures. This may be considered as looking too far into the future, but any scale adopted should be capable of indefinite extension without abandoning the scale for the fuels of the present. (See S.A.E. HANDBOOK, p. 607.)

Throughout this statement, where the word "octane" is used, the reference is to iso-octane (2, 2, 4, tri-methyl pentane).

[2] For the present the engine will include, as standard equipment, a bouncing-pin and gas-evolution cell. The knockmeter may be supplied on the purchaser's request, at additional cost.

[3] The question of spark-plugs and spark-plug gaps is being studied and the present recommendation is subject to change.

[4] At present heptane and octane may be obtained from the Ethyl Gasoline Corp., 320 Yonkers Avenue, Yonkers, N. Y., at a price of $25 per gal. each. Recently two secondary standards have become commercially available through the Standard Oil Co. of New Jersey. These fuels have octane numbers of 50 and 68 respectively, and calibration curves are furnished with them (as determined on the Ethyl Gasoline Corp. Series-30 Knock-Testing engine with the bouncing-pin), giving octane numbers for these fuels blended with each other and with chemically pure benzene or tetraethyl lead. For tests of motor fuels, the data were obtained with very definite operating conditions and technique at a cylinder-cooling-medium temperature of 212 deg. fahr. These fuels are supplied at 80 cents per gal. in 50-gal. lots or $1 per gal. in 5-gal. lots. They may be ordered through Ross H. Dickson, Standard Oil Development Co., Room 734, 26 Broadway, New York City.

of heptane and octane, the results should be recorded as an octane number.

7.—Knock Intensity

A tentative recommendation may be made that the knock intensity for use with the bouncing-pin should be found by determining the compression ratio at which incipient knock occurs, and then increasing the compression ratio by 1.0 unit[5].

Experience on the engine may make it necessary to change this recommendation.

8.—Mixture-Ratio Adjustment

When using the knockmeter it is unnecessary to take readings over a fixed period of time. To find the adjustment for maximum knock, note the meter reading and the micrometer setting. Then turn the micrometer screw and note whether the meter readings go up or down. Slowly turn the micrometer in the direction in which the knock increases until the knock passes through a maximum. Check the point at least three times and set the micrometer at the position of maximum knock.

When using the gas-evolution burette, two readings over a period of 1 min. each should be taken as a measure of knock intensity. The carbureter is adjusted to the maximum-knock position, as in the preceding paragraph, by turning the micrometer and taking two 1-min. readings at each position.

Next place a blend of the low reference fuel and the high reference fuel in another gasoline container, estimating the proportions by the expected knock rating of the unknown fuel. Adjust the micrometer for this float-bowl to the maximum-knock position as indicated above.

9.—Antiknock Determination

With the float-bowls thus set for maximum knock, take alternate readings on the two fuels. At least 1 min. should be allowed after changing from one fuel to another to allow the engine to reach equilibrium, and with certain fuels an appreciably longer interval is required. When using the knockmeter, the needle should be allowed to become stationary before the reading is recorded. When using the gas-evolution burette, at least two successive 1-min. readings should agree.

Take at least three alternate readings on each fuel. If the average of the readings on the unknown sample is higher than the average on the reference-fuel blend, repeat the readings with a blend containing a greater proportion of the high reference fuel. Continue in this manner until the readings on the sample are definitely higher than one blend and lower than another blend. For this bracket a value of two octane numbers is recommended as representative of the size now used by most laboratories[6]. The antiknock value of the sample is obtained by interpolation of the figures so recorded, and is reported as the nearest whole number.

When changing fuels in the containers, drain the previous fuel completely by means of the drain-cock provided. Allow a small portion of the new fuel to flow through the line befor closing the drain-cock.

10.—Maintenance

In the operation of the testing apparatus, it is recommended that a systematic schedule of inspection be carried out with the utmost care. Weekly inspections may be found advantageous from the standpoint of consistency of results.

Bouncing-Pin.—Tighten diaphragm retaining nut and clean off any carbon accumulation. In time the diaphragm will lose its temper and need replacement. These conditions manifest themselves by an irregular gas evolution or lack of sensitivity.

Breaker-Point Clearance.—The breaker-point clearance should be checked and any pits which have formed dressed off.

Spark-Plugs.—The spark-plugs should be cleaned and the porcelain inspected for cracks. The gap should be checked.

Fuel System.—Flush out the fuel system and make sure there is no accumulation of foreign matter in the fuel containers, float-bowls, lines or carbureter.

Cooling System.—Inspect for leaks, tighten or replace the pump packing as required.

Combustion-Chamber.—Inspect piston and cylinder-head for character of carbon deposits. Excess carbon should be removed mechanically.

Compression Pressure.—The compression pressure while motoring at 600 r. p. m. should be checked with a compression gage. The cause of any abnormal change between inspections should be investigated and corrected.

Valves.—Tappet clearances should be checked and valves reground when not seating.

APPENDIX A

Engine and Bouncing-Pin Adjustment

Adjustment of Bouncing-Pin

(a) The current flowing through the bouncing-pin circuit at a given knock intensity is determined by the voltage applied, the clearance between the gaps, and the adjustment and physical properties of the diaphragm and the various springs. It has not been found possible to manufacture pins of identical characteristics. No definite systematic instructions for adjustment have been found which will always secure the desired result. A description of the procedure may be illuminating.

The engine is operated on a fuel of 74 octane number under standard conditions. Sixty readings are taken from the knockmeter at 10 record intervals. The *greatest difference* between any two of the 60 readings is recorded, together with the *average difference* of consecutive readings, known as the stability. The *stability factor* is defined as the product of the greatest difference by the stability.

The engine is then checked for quality of knockmeter readings with the same fuel on both sides of the carbureter, and is then operated on a fuel differing from the first one by about 0.5 octane number (74.5).

The *sensitivity* is the difference in average knockmeter readings for the fuels of 74 and 74.5 octane number.

The *pin factor* is then defined as the ratio of the *sensitivity* to the *stability factor*. The pins are adjusted until they show a pin factor of about 5.0 under the specified conditions, and are then considered to give good knock-testing operation.

Quite satisfactory knock testing may be secured with pins showing a pin factor of much less than 5.0, provided the highest degree of precision (fractions of an octane number) is not required.

The following data represent the average of 30 bouncing-pins after adjustment:

Greatest difference in knockmeter readings, 3.6.
Stability, 0.45.
Stability factor, 1.70.
Sensitivity, 8.4.
Pin factor, 4.95.

The pin factor may be greatly changed by very small changes in adjustment of the pin. These changes include adjustment of tension of the plunger spring above the contacts, adjustment of the tension of the two leaf-springs leading from the contacts, and adjustment of the gap between the contacts. It is not advisable for the inexperienced operator to attempt to adjust the various springs, but if the pin does not give satisfactory performance, the operator should operate the engine alternately on fuels differing by one octane number, and then adjust the bouncing-pin gap, making changes of less than 0.001 in. at a time and measuring the pin factor for each adjustment. A gap of 0.007 to 0.009 in. usually gives the best results, but a difference of 0.001 in. may sometimes make all the difference between satisfactory and unsatisfactory results.

(*Concluded on p.* 168)

[5] Details of adjustment of the bouncing-pin and instructions for dealing with difficulties in its operation are contained in Appendix A.

[6] This tentative recommendation is made with the understanding that the bracket size will be changed when and if further research so justifies.

Transportation Engineering

Effective Traffic-Control

Different Types of Control Systems Defined and Advantageous Features of Each Stated

TRAFFIC-CONTROL systems that are highly efficient are now demanded by the public to replace systems which merely "handle" traffic. Four different types of system have been developed to meet this demand, according to C. A. B. Halvorson, of the General Electric Co., who outlined them as follows at a recent meeting of the New England Section.

The *flexible progressive system* has the highest efficiency for moving traffic at a predetermined speed along both through and cross streets, he said, and at the same time makes possible an adjustment of the timing at each intersecting street to take care of traffic demands at that particular intersection. A very recent development of this type of control permits a setting of an ideal progression "in" to a city during the morning, "out" from the city in the evening, and an average progression both ways throughout the day. The selection of the progression desired is made at a central control-point by moving a switch, and this can be done automatically. A modification of this system—one which is much cheaper to install because interconnecting cable is not necessary—is obtained by using synchronous motor drive in the timers. This type of control has many of the advantages of the flexible progressive system, but the total cycle cannot be varied except by manual adjustment at the timer.

The *limited progressive system* in which all signals change simultaneously but alternate signals or groups of signals show opposite colors allows a reasonable amount of progression. It does not permit of variations in setting according to demands at various intersections, but it will allow a variation in total time-cycle; that is, the percentage split of the total cycle is the same at each intersection throughout the entire system.

The *synchronized system* allows no continuous progression, since all signals change at the same time, and it encourages the motorist to speed in an attempt to pass as many signals as possible.

Isolated intersections have always been a problem, but many new developments are greatly increasing the efficiency of signal control at such intersections. Where the ratio of traffic on the main street to that on the cross street is comparatively high, the *traffic-actuated control* offers a signal which minimizes delay especially when the traffic flow is light, although the development of a plan whereby the principle of progressive control is applied to isolated intersections bids fair to be as efficient and has the advantage of not using any mechanism in the street surface. Under this system vehicles are not brought to a complete stop, but are simply slowed down to pass the intersection at a safe speed.

The problem is becoming more acute each year as the highways carry increasingly heavy traffic and as the number of accidents grows greater. No longer is it sufficient to place a signal at a dangerous intersection; the conditions at such a point must be studied, the times at which control is needed taken into consideration and the right type of system employed.

Higher Motor-Vehicle Taxes

Taxation Expert Says Adequate Fees Are Now Paid—Deplores "Equalizing" Rail and Highway Taxes

INCREASING levies on motor-trucks and motorcoaches for the purpose of equalizing taxes between road and rail carriers would offset the natural advantages of the highways and work a hardship on automobile owners, declared John E. Walker, former special assistant on taxation to the Secretary of the Treasury, at a recent meeting of the National Petroleum Institute at Cleveland.

The former Government official pointed out that the motor-vehicle tax-bill, which accounted for 78 per cent of the $726,000,000 State-highway income for 1929, clearly indicates that the motorist is not subsidized by the public. Only 10 per cent of this income was derived from combined general property taxes, appropriations and miscellaneous sources.

Claims that railroads are subsidizing their highway, competitors were also discredited by Mr. Walker in pointing out that the $4,500,000 rail burden for State roads in 1929 represented but 0.5 per cent of the State-highway income, and was only 1.1 of the total rail-tax payment. The railroads paid nothing directly toward State-highway programs in 21 States during that year, he said. Continuing, he remarked that:

> The use of the motor-vehicle has greatly expanded the distribution area which could be covered with the horse and wagon. It has developed a great network of highways.
>
> There is no justification for increasing taxes upon motor-vehicle owners except as the needs of the highway budget may require.
>
> The charge is made that the passenger-car owners are paying more than they should of the total road-cost and thereby subsidizing commercial use of the highway. Has it ever occurred to you what would be the situation if the commercial vehicle, truck and bus, had never been permitted to use the road? You can visualize as well as I can that one of two things would have happened. Either we would not today have had as great mileage of improved roads available to the passenger-car user, or the car user would have paid more and would have continued to pay more for the extensive mileage now available.
>
> I do not agree with the theory of "equalizing" taxes between rail and road. The public, convinced that it gets a service and a value received from the commercial user of the road, and likewise convinced that he is making substantial tax payments toward the construction and upkeep of the roads he uses, will, I believe, be more inclined to encourage than to discourage such use of the road.—*Highway Spokesman.*

Model State Laws Reduce Accidents

AT A MEETING of the Conference Executive Committee of the National Automobile Chamber of Commerce held in June, it was reported that the ratio of traffic fatalities has been lowered as much as 25 per cent in some States through the enactment of drivers'-license, compulsory-inspection, financial-responsibility and other model legislation, such as has been recommended by the National Conference on Street and Highway Safety. Based on educational activities which already have lowered the number of motor-vehicle accidents involving railroads and commercial vehicles, the Conference believes that the work during the next few years should bring a substantial reduction in highway fatalities.

(*Concluded on p.* 168)

Production Engineering

Gluing in Aircraft Construction

Materials, Preparation and Making of Joints Described by T. R. Truax[1] at Wichita

WE READ and hear a great deal about the place of wood in aircraft and the probability that it will be replaced by metal and other materials; nevertheless, wood is still an important structural material for aircraft. High strength in relation to its weight, ease of working and repair, and adaptability for small-scale production methods are among the well-known properties of wood, and the durability of the wood itself compares well with that of other materials. These considerations indicate that wood will hold a place in aircraft construction for a number of years to come. However, if wood is to continue as a principal structural material for aircraft, it must pass from small-scale production to large-scale production, presumably involving standardization of processes and production in multiple units.

One of the principal problems in connection with wood in aircraft is fastening pieces of it together so as to utilize its full strength. Glue has long been recognized as one of the most effective fastenings for wood. In actual practice, however, parts containing glued joints often fail in the glue line and such joints are generally regarded as the weakest points in aircraft structures. The object of the research work at the Forest Products Laboratory on glues and gluing has been to make joints in wood as strong as the wood itself. Our tests indicate that well-made glued joints will remain permanent in strength under ordinary conditions of exposure, but that they are not permanent unless well made.

Materials and Their Preparation

Certain definite requirements must be met to make satisfactory joints. The first is that the wood must be properly dried and conditioned to avoid the stresses that result from unequal changes in the moisture content of the wood in the various laminations. For example, the several laminations in a wood propeller must all have approximately the same moisture content at the time of gluing to produce serviceable propellers. Higher water resistance can be obtained in water-resistant plywood if the wood is glued with a higher moisture content than is common in most veneer gluing operations. For the best strength of plywood under both dry and wet conditions, the veneer before gluing should have a moisture content of 8 to 12 per cent. Likewise, the wood used in laminated beams and other parts of airplanes must be carefully dried and conditioned before gluing.

A perfectly smooth, flat wood surface is most satisfactory for gluing; a roughened, irregular surface is unsatisfactory. In other words, it is unnecessary to pull out fibers of the wood to give the glue a chance to adhere. Glued tongued-and-grooved and other irregular shaped joints are normally not more efficient than flat joints; but joints in end-grained sections or pieces of wood can be made somewhat stronger by an increase in contact area, preferably by a long scarf. Ordinary straight joints are the best for gluing side-grained surfaces.

Casein glue is most commonly used in the aircraft industry, but blood glue is used to a small extent for gluing plywood. Blood glue would no doubt be used more extensively if it did not require the application of heat to the joints, which causes a certain degree of inconvenience. Hide, or animal, glue is also used to a small extent, but it does not resist the action of water as well as casein or blood glues. Hide glue, however, is satisfactory for wood propellers because the admission of moisture in quantities sufficient to injure the glued joint would also cause the propeller to warp enough to make it useless; therefore, highly moisture-resistant coatings are used to protect the whole construction.

Mixing and Applying the Glue

Mixing is very important in the preparation of glue. The glue solution must be uniform in consistency, well dissolved and mixed, and must not be allowed to decompose. Air should not be whipped into the glue during mixing. Foamy glue is especially objectionable in operations where light pressures are applied in gluing the joints.

Assuming that well-dried wood and properly mixed glue are available, the important job is that of making good joints under production conditions. The glue must be given a fair chance or the joint will be only 50 to 75 per cent effective and it may fail later under load. The general rule is that the consistency of the glue and the gluing pressure used must be in proper relation. A good joint cannot be made with thick glue and insufficient pressure. The water in the glue must come into intimate contact with the wood to secure satisfactory adhesion. It is just as disastrous to use thin glue and too much pressure. This condition prevails more commonly with animal glue and older methods of gluing. A tradition of gluing has been to keep animal glue quite warm and thin. Many joints produced in this way develop only about 50 per cent of their possible strength. A distinct glue line is characteristic of a good glued joint.

The quantity of the glue spread must be adequate and it must be uniformly spread. There is more danger of using too little than too much glue. A fairly liberal application of glue is advisable. The principal harm of an excess of glue is the addition to the wood of more moisture than is necessary.

The time required for assembly, that is, the time between the spreading of the glue and the application of pressure to the joint, must also be properly controlled. Early pressure is important in making a joint. A range of from 1 to 12 min. can be allowed with casein glue if adequate pressure is available. If sufficient pressure cannot be applied, the time of assembly must be kept down to the minimum.

Pressure Often Is Insufficient

No specific pressure can be said to made the best joints under all conditions. An analysis of about 4000 joint tests on 24 different woods, made by charting the weak joints, showed some interesting results. Very few weak joints were found among those that were assembled in between 1 and 12 min. after spreading the glue, using a pressure of 200 lb. per sq. in. About four times as many weak joints were found among those that were assembled in the same time when using a pressure of 50 lb. per sq. in.; and with longer assembly times and low pressure the proportion of weak joints was still larger. As a rule, the best procedure in gluing all kinds of wood is to use a relatively thick glue and heavy pressure. Spruce may crush at about 300 lb. per sq. in.; hence gluing pressures used on it should be well under this amount. A reliable and safe pressure to use on spruce is 100 to 150 lb. per sq. in. Unfortunately, much of the equipment that is used in aircraft operations at present does

[1] Senior wood technologist, U. S. Department of Agriculture; now stationed at the Forest Products Laboratory maintained at Madison, Wis., in cooperation with the University of Wisconsin. Abstract of Mr. Truax's address.

not apply that much pressure; in fact, enough pressure is seldom used.

The glue should be slightly thinner for joints in which small nails are the only means of pressure than for joints glued in power presses. Extensive tests on about 40 different native woods show that all the species commonly used in aircraft can be glued successfully with proper gluing conditions. No difficulty was encountered in making joints in spruce so strong that, when broken, the failure was in the wood 98 to 99 per cent of the time rather than in the glue line. In ash, birch, and other high-density species, more care and closer control of the gluing operation are necessary to obtain the full strength of the wood. Mahogany and yellow poplar are intermediate between the more easily glued and the more difficult dense hardwoods. Slightly thicker glue should be used in uniting maple or birch to spruce than in gluing spruce to spruce.

Protection of Joints from Moisture

Research has been carried on at the Forest Products Laboratory to find ways and means of making glued joints more permanent under conditions of service. Coatings of various kinds are known to reduce periodic changes in the moisture content of wood in service and thus to lessen the shrinking and swelling stresses on glued joints. Such materials have been extensively used in aircraft construction and are helpful. They do not, however, present deterioration of the joints under severe service conditions; for example, such as the prolonged exposure to very high humidities or to water that may occur in seaplane hulls and floats. Even the most water-resistant blood-albumin and casein glues fail in time under continuous exposure to water or saturated atmosphere. In fact, under conditions where wood retains 20 per cent or more of moisture, there is no positive assurance of the permanence of glues without special treatment.

As a result of experiments, special treatments have been discovered that materially increase the durability of glued joints under the most severe conditions. The treatments are of three general kinds, namely: (*a*) addition of preservative materials to the glue before making the joints, (*b*) preservative treatment of joints that are glued with untreated glues, and (*c*) treatment of glues before making joints, followed by the application to the glued joints of aluminum powder in spar varnish, which is a fairly effective moisture-excluding coating. All three forms of treatment are decidedly beneficial, but treating the joints with a preservative after gluing has been thus far the most effective and has doubled or trebled the serviceable life of the joints. Tests, which are still incomplete, indicate that glued joints can be made sufficiently durable to last throughout the life of an airplane, even under adverse conditions of exposure. A more complete discussion of the making of satisfactory glued joints and their protection by special treatments is given in Technical Bulletin No. 205, of the United States Department of Agriculture, entitled, Gluing Wood in Aircraft Construction.

Automotive Research

(*Concluded from p.* 165)

Difficulties

Some of the difficulties that may be encountered are listed below and remedies which may be helpful in each case are suggested in the parallel column.

Difficulty	Remedy Suggested
Gas evolution too large, acid becoming entrained above the gas in the graduated burette	(*a*) Reduce degree of knock by lowering compression ratio or by closing throttle (*b*) Examine bouncing-pin diaphragm and make sure that it is seated squarely and the retaining nut made fast
Gas evolution too small	(*a*) Increase degree of knock by raising compression or opening throttle (*b*) Examine pin and make sure that it is clean and free to move
Bouncing-pin readings have a tendency to drift in one direction	(*a*) It is possible that equilibrium temperature has not yet been reached. Continue to take readings for 10 min. Readjust compression-ratio or throttle as necessary until readings become constant
Bouncing-pin readings vary over such a wide range that sensitivity is obscured	(*a*) Make sure that there is no entrained air or gas bubbles or dirt in the carburetion system (*b*) Make sure that the contact surfaces are clean (*c*) Examine the diaphragm and clean the pin with kerosene (*d*) Examine the pin in the contact adjusting-screw and make sure that it is not binding at times
Engine missing. Missing cannot be tolerated. An engine that misses only once every hour cannot be used for knock testing.	(*a*) Examine ignition system for (1) leaks to ground, (2) carbon on spark-plug, (3) spark-plug points too far apart, (4) test spark outside of engine to make sure that the coil is in good condition, (5) examine breaker system for loose parts.

Transportation Engineering

(*Concluded from p.* 166)

It was agreed that the efforts of highway commissioners to provide safe highways, of traffic officers to formulate standardized traffic regulations, and of motor-vehicle manufacturers to build safer vehicles are contributing their share toward accident reduction, but there is still a great need for educating pedestrians and motor-vehicle drivers. Stress was laid on the importance of educating high-school children who are now approaching the age when they will soon be driving motor vehicles. The Conference was also encouraged by the success of driver-training programs for commercial-vehicle operators, which resulted in a reduction of approximately 20 per cent in the number of accidents for such vehicles in 1930.

The average interstate bus pays $739.27 in special taxes annually, according to the National Association of Motor Bus Operators. — *Highway Spokesman.*

Section Officers for 1931-1932

(*Concluded from p.* 107)

Vice-Chairman—Chester S. Ricker, president, Day-Nite, Inc., Waukesha, Wis.

Treasurer—Charles W. Kramlich, Jr., sales engineer, Fafnir Bearing Co., Milwaukee.

Secretary—Wesley B. Pusey, sales engineer, S.K.F. Industries, Inc., Milwaukee.

New England Section

Chairman—Robert F. Lybeck, manager wholesale gasoline and motor-oil sales, Colonial-Beacon Oil Co., Inc., Boston.

Vice-Chairman—Dean A. Fales, associate professor of automotive engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Treasurer—A. E. Postal, service manager, United Motors Service, Inc., Boston.

Secretary—Fred W. Herlihy, sales manager, New England district, Shell Eastern Petroleum Products, Inc., Boston.

Northern California Section

Chairman—Howard Baxter, Howard Baxter Automotive Service, Oakland, Calif.

Vice-Chairman—Arthur B. Domonoske, executive head, mechanical engineering department, Leland Stanford Junior University, Stanford University, Calif.

Vice-Chairman for East Bay—Edward Maybem, superintendent of equipment, City of Berkeley, Berkeley, Calif.

Treasurer—C. J. Vogt, instructor in mechanical engineering, University of California, Berkeley, Calif.

Secretary—William S. Crowell, manager of claims, Edward Brown & Sons, San Francisco.

Northwest Section

Chairman—C. H. Bolin, general motor-vehicle supervisor, Pacific Telephone & Telegraph Co., Seattle, Wash.

Vice-Chairman—James H. Frink, assistant to manager, Washington Iron Works, Seattle.

Treasurer—Charles C. Finn, northwest agent, John Finn Metal Works, Seattle.

Secretary—John G. Holmstrom, chief engineer, Kenworth Motor Truck Corp., Seattle.

Oregon Section

Chairman—H. W. Drake, superintendent of garage, Portland Gas & Coke Co., Portland, Ore.

Vice-Chairman—H. W. Roberts, secretary, treasurer, Roberts Motor Co., Portland.

Treasurer—J. Vern Savage, superintendent, Municipal Shop, City of Portland, Portland.

Secretary—M. T. Clark, branch manager, Laher Auto Spring Co., Inc., Portland.

Philadelphia Section

Chairman—W. Laurence Le Page, chief engineer, Kellett Aircraft Corp., Philadelphia.

Vice-Chairman—J. P. Stewart, head, automotive laboratory, Vacuum Oil Co., Paulsboro, N. J.

Treasurer—Lyman Colt Josephs, Jr., engineer in charge, Mack plant, International Motor Co., Allentown, Pa.

Secretary—Earl D. Sirrine, transportation engineer, Autocar Co., Ardmore, Pa.

Pittsburgh Section

Chairman—B. H. Eaton, motor-vehicle supervisor, western division, Bell Telephone Co. of Pennsylvania, Pittsburgh.

Vice-Chairman—C. R. Noll, automotive lubrication engineer, Gulf Refining Co., Pittsburgh.

Treasurer — Murray Fahnestock, technical editor, *Ford Dealer and Service Field*, Pittsburgh.

Secretary—Clyde C. Mathis, district service manager, White Co., Pittsburgh.

St. Louis (Probationary)

Chairman—A. J. Mummert, secretary, chief engineer, McQuay-Norris Mfg. Co., St. Louis.

Vice-Chairman—G. C. Stevens, manager, St. Louis branch, Diamond T Motor Car Co., St. Louis.

Treasurer—Robert M. Pease, manager, St. Louis factory, engine overhaul and service, Axelson Aircraft Engine Co., St. Louis.

Secretary—William G. Jenkin, president, Jenkin-Guerin Oil Co., St. Louis.

Southern California Section

Chairman—Wendell E. Mason, assistant professor of applied mathematics, University of California, Los Angeles.

Vice-Chairman—Harold T. Ramsay, automotive engineer, Standard Oil Co. of California, Los Angeles.

Treasurer—J. Jerome Canavan, vice-president Southern California National Corp., Ltd., Los Angeles.

Secretary—C. H. Jacobsen, service manager, Moreland Motor Truck Co., Los Angeles.

Syracuse Section

Chairman—Charles P. Grimes, manager, Grimes Brake Engineering Service, Syracuse.

Vice-Chairman—Richard N. Wright, service manager, Hubert J. Wright, Inc., Syracuse.

Treasurer—Melville R. Potter, service manager, Allen Cadillac Corp., Syracuse.

Secretary—Lloyd W. Moulton, manager, Manufacturers' Consulting Engineers, Syracuse.

Washington Section

Chairman—William P. MacCracken, Jr., partner, MacCracken & Lee, City of Washington.

Vice-Chairman—Carlyle S. Fliedner, technical adviser, powerplant design, Bureau of Aeronautics, Navy Department, City of Washington.

Treasurer—Edward S. Pardoe, superintendent of bus operations, Capital Traction Co., City of Washington.

Secretary—John C. McCalmont, associate aeronautic engineer, Bureau of Aeronautics, Navy Department, City of Washington.

Wichita Section

Chairman—H. Fletcher Brown, chief draftsman, Curtis Wright Airplane Co., Wichita, Kan.

Vice-Chairman—Rex B. Beisel, vice-president, chief engineer, Spartan Aircraft Co., Tulsa, Okla.

Treasurer—Lewis G. Sinning, manager purchasing and planning, Stearman Aircraft Co., Wichita.

Secretary—Eldon W. Cessna, assistant chief engineer, Cessna Aircraft Co., Wichita.

Leo I. Heintz

ANNOUNCEMENT of the death of Leo I. Heintz, president of the Heintz Mfg. Co., of Philadelphia, on July 8, is made with sorrow by the officers and directors of the company.

Mr. Heintz had been connected all his business life with the machine and metal-working industries allied with the automobile industry as supplier, and was president of the Heintz company for nearly 10 years, engaged in the production of automobile bodies and metal stampings. He was born at Bridgeton, N. J., in 1879, and from 1899 to 1901 was a designer on power presses and dies for the Ferracute Machine Co., of Bridgeton. The following two years he was superintendent of the Grand Rapids Brass Co., of Grand Rapids, Mich. During the next nine years he held the same position with the Hale & Kilborn Co., of Philadelphia, producing car seats and stampings. He held the post of works manager of the Edward G. Budd Mfg. Co., in Philadelphia, for the nine years preceding his election to the presidency of the Heintz company.

Mr. Heintz was elected to Member Grade in the Society in December, 1923, and was a member of the Pennsylvania Section and also of the Engineers Club of Philadelphia.

Frank N. Nutt

WITH the passing on of Frank N. Nutt at Rochester, Minn., on June 24, following a year's illness, the industry has lost another of its pioneer workers and the Society a member of 21 years' standing. His loss will be deeply regretted by a host of friends.

Mr. Nutt had been connected with the A. C. Spark Plug Co., of Flint, Mich., since 1924, first as consulting engineer and since 1926 as experimental research engineer. He was for several years a member of the Detroit Section. Prior to joining the spark-plug company, he had been chief engineer of the Haynes Automobile Co., of Kokomo, Ind., for 15 years. His association with this early automobile company began in 1899, being his first professional connection following his graduation from high school in Los Angeles, in which city he was born in October, 1879.

In the early days of automobile development, Mr. Nutt took part in the Vanderbilt Cup Races on Long Island, being located at the New York City branch of the Haynes company during the years 1904 and 1905.

Several papers have been contributed by Mr. Nutt at meetings of the Society. The first, entitled Shifting Gears by Electricity, was published in the S.A.E. BULLETIN for December, 1913, p. 283, and in TRANSACTIONS, Part 1, 1914, p. 177. Another paper on the same subject was published in the S.A.E. BULLETIN for May, 1914, p. 122, and in TRANSACTIONS for that year, Part 2, p. 253. At the October, 1928, meeting of the Indiana Section, he presented a paper on the A. C. diaphragm-type fuel-pump.

Louis G. Meister

REPORTS of the death on July 19 of Major Louis G. Meister at the Wayne County Airport, near Detroit, came as a shock to the aeronautic fraternity and caused much sorrow among his friends and acquaintances. He was making a final test flight of a new airplane that he had been testing for a week and is reported to have put it into a spin from which he was unable to recover. Abandoning the plane at an altitude of about 1000 ft., he apparently delayed pulling his parachute cord too long.

Major Meister was in charge of military sales for the Verville Aircraft Co., of Detroit, and was to have reported at Selfridge Field, Mich., on the day of his accident for a two-weeks' period of duty as a reserve officer attached to the Army Air Service first pursuit group. He had been in the Air Service from 1917 to 1926, as first lieutenant, engineering officer, at Scott Field and in the engineering division at McCook Field engaged in flight-performance testing and armament design and testing in airplanes, and, in 1926, as chief of the Airways Branch, stationed at McCook Field, Dayton, Ohio.

Resigning from the Service in 1926, Major Meister joined the Buhl Aircraft Co., of Marysville, Mich., as sales manager, a position he retained until the latter part of 1929, when he became vice-president and manager of the Curtiss Flying Service of Ohio, in Cleveland. He transferred his connection to the Verville Aircraft Co. before the beginning of this year.

Born in New York City in June, 1890, Major Meister received his technical education at Teachers' College, Columbia University, Cooper Union, the Massachusetts Institute of Technology and the Air Service Engineering School. He was admitted to the Society as a Service Member in June, 1920, and while at McCook Field was a member of the Dayton Section.

William Joseph Duffy

ONE of the best known automotive transportation men in New England passed to his rest when William Joseph Duffy, of Boston, died suddenly in June following an attack of appendicitis.

Mr. Duffy had been vice-president and general manager of Big 3, Inc., and inspector of the Boston & Maine Transportation Co. since 1928. Prior to that time he had served the Fall River, Mass., trucking firm of E. P. Winward & Son from 1920 to 1925 in various capacities, rising rapidly from the position of helper in loading and unloading trucks to assistant to the general manager. In 1926 he became assistant to the president of Stone's Express, Inc., in charge of operations and of negotiations with the Boston & Maine Railroad Co. and the Boston & Maine Transportation Co. He combined Stone's Express and the Massachusetts Motor Trucking & Garage Co. in the interest of the Boston & Maine Transportation Co. and the contractors and took charge of the operations of both.

Mr. Duffy was born at Fall River, Mass., in 1895 and was educated at the Holy Cross College in Worcester, Mass., and at the Academie Maine et Loire in France. He was admitted to Member grade in the Society in April, 1929, and was a member of the Transportation Committee in 1929 and of the Transportation and Maintenance Committee in 1930 and 1931.

Edward A. Ross

WHILE on a business trip to Europe in the first part of July, Edward A. Ross, president of the Ross Gear & Tool Co., of Lafayette, Ind., was suddenly taken ill on the steamship and was obliged to undergo two operations upon his arrival in London. He was unable to survive the second one and succumbed on July 9.

The passing of Mr. Ross will be lamented by many long-standing members of the Society, of which Mr. Ross became a Member in November, 1910. He was born at Lafayette in December, 1883, and received his technical education at Purdue University. When the Ross Gear & Tool Co. was formed in 1906 he became secretary and engineer of the company and retained the office of secretary until being elected president in 1927. For a number of years he served as sales manager as well as secretary. He was a member of the Indiana Section for many years.

Personal Notes of the Members

Fokker Forming International Company

At a meeting of the directors of the General Aviation Corp. in July, an agreement was reached whereby A. H. G. Fokker resigned as director of engineering of the corporation and retains the right to use of the name Fokker, Mr. Fokker's employment contract and the contract which the General Aviation Corp. had with the Dutch Fokker Aircraft Co. being terminated. Mr. Fokker continues as a director and large stockholder of the General Aviation Corp. but is free to devote his attention to the formation of the International Fokker Corp., which is to bring into one organization the interests of companies throughout the world engaged in manufacturing airplanes under Fokker licenses. The nucleus of the new company is to be the Dutch Fokker Aircraft Co., and control will be exercised through it over aircraft manufacturing companies licensed by it in Great Britain, France, Belgium, Italy, the Scandinavian countries and the Balkan States. Mr. Fokker is interested also in European air lines using Fokker planes exclusively and plans to bring them into the combination.

Albert A. Gassner, formerly chief engineer of the General Aviation Corp. and the Fokker Aircraft Corp., will join the new Fokker Corporation.

Keilholtz Makes a Change

Lester S. Keilholtz, who was technical assistant to the president of the Frigidaire Corp., in Dayton, Ohio, is now general research manager for Montgomery Ward & Co., in Chicago. Nearly all of his professional life he has been concerned with work on internal-combustion engines and electrical apparatus specializing during the last 20 years on electric engine-starters, small electric-lighting plants and electric refrigerators. In 1907, after being graduated with the degree of Mechanical Engineer by the Ohio State University, he was gas-engine tester for Fairbanks, Morse & Co., at Beloit, Wis. He was then connected with Thomas B. Jeffery & Co., at Kenosha, Wis., on the assembly and testing of automobiles for 1½ years, and with the National Cash Register Co., at Dayton, Ohio, as draftsman for 2½ years. For the five years from 1911 to 1915 he was chief draftsman on Delco starters for the Dayton Engineering Laboratories Co. His connection with lighting plants began in 1916 with the Domestic Engineering Co., of Dayton, as chief engineer, and from 1921 to 1928 he held the same position with the Delco-Light Co. From 1921 to 1929 he was also chief engineer of the Frigidaire Corp., and in the last named year became technical assistant to the president of that company.

Mr. Keilholtz was admitted to Member grade in the Society in August, 1917, and joined the Dayton Section in 1920. In 1919 he was Second Vice-president of the Society, representing stationary internal-combustion engineering and in 1926 was a member of the Engine Division of the Standards Committee.

Thaden Now Fokker Factory Manager

In a reorganization of the Fokker Aircraft Corp. of America last month, H. V. Thaden, formerly vice-president and general manager of the Metalair Corp., of Pittsburgh, was placed in charge of the Fokker company's manufacturing division as factory manager and acting chief engineer. In the latter position Mr. Thaden succeeds Alfred A. Gassner, who held the position for several years. The Fokker corporation is a subsidiary of the General Aviation Corp., of which J. M. Schoonmaker, Jr., is president.

Mr. Thaden, who became a Junior Member of the Society in 1921 and is now an Associate Member, has been successively since then a mechanical and aeronautical engineer in Detroit, chief design engineer with the Aircraft Development Corp. in Detroit, vice-president and general manager of the Thaden Metal Aircraft Corp., of San Francisco, vice-president and general manager of the Pittsburgh Metal Airplane Co. and vice-president and general manager of the Metalair Corp.

Foulois Raised to Major General

In July the War Department announced among other promotions in rank the raising of Brig.-General Benjamin D. Foulois, assistant chief of the Army Air Corps, to the rank of Major General, the promotion being approved by the President upon the recommendation of the Secretary of War. General Foulois is to succeed Major-General James E. Fechet when the latter retires upon the expiration of his four-year detail as chief of the Air Corps on Dec. 19.

General Foulois probably was the first aviator in the United States Army and as a pioneer in aviation studied it in all its phases, particularly engines, in the early days of its development. He has been associated with aeronautics in the Army and in Air Service development work ever since its beginning, and is generally regarded as the father of military aviation. He was born at Washington, Conn., in December, 1879, and became an Associate Member of the Society in October, 1925.

W. B. Barnes Joins Schwitzer-Cummins

William B. Barnes, who had been in charge of research and experimental work for the Auburn Automobile Co. since 1927, is now consulting engineer for the Schwitzer-Cummins Co., of Indianapolis. He has been a Member of the Society since May, 1928, and a member of the Front-Wheel Alignment Subcommittee of the Research Committee for the last three years. He received the degree of Bachelor of Science in Mechanical Engineering in 1920 from Purdue University, where he was instructor in internal-combustion engines in that year, and in 1924 he was awarded the professional degree of Mechanical Engineer by the University. His professional connections have been with the Cadillac Motor Car Co., as laboratory assistant on experimental and research work; the Wheeler-Schebler Carbureter Co., as assistant engineer on carbureter design and research; the Big Four Railroad, as automotive engineer in charge of rail-car maintenance; the Flint Motor Co., in charge of road tests; the International Harvester Co., in charge of carbureter development; and the Auburn Automobile Co., as experimental engineer.

Lawrance Presents Post-Gatty Plaques

Special twin bronze plaques in recognition of their flight around the world in less than nine days were presented to Wiley Post and Harold Gatty by Charles L. Lawrance, president of the Aeronautical Chamber of Commerce of America, at a banquet given to the globe-girdlers by the Chamber in New York City on July 7. Many of the most famous men in aeronautics and aviation in America were among the nearly 500 persons who attended the banquet. Among members of the S.A.E. in attendance were Clarence M. Young, Assistant Secretary of Commerce, who represented President Hoover; Harold H. Emmons, vice-president of the Detroit Aircraft Corp. which built the Winnie Mae Lockheed airplane used by Post and Gatty; E. A. Deeds, chairman of the board of the United Aircraft & Transport Corp.; A. V. D. Willgoos, chief engineer of the Pratt & Whitney Aircraft Co., builder of the

(*Continued on p.* 40)

Applicants Qualified

The following applicants have qualified for admission to the Society between May 10 and July 10, 1931. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff.) Affiliate; (S M) Service Member; (F M) Foreign Member.

ANDERSON, W. F. (J) sales engineer, industrial division, Timken Roller Bearing Co., Canton, Ohio; (mail) 2534 South Michigan Ave., *Chicago.*

AVILEZ, IGNACIO (M) head, machinery department, National Highway Commission, professor, heat engines, National School of Engineers, *Mexico, D. F.;* (mail), Carpio 103.

BANDEL, CHARLES A. (A) branch sales manager, Overman Cushion Tire Co., Inc., New York City; (mail) 1023 Calvert Building, *Baltimore.*

BANKS, FRANCIS RODWELL (F M) technical representative, Ethyl Gasoline Corp., Abford House, Victoria, *London, England.*

BAUER, NORMAN G. (J) electrical design draftsman, International Harvester Co., *Fort Wayne, Ind.;* (mail) 1739 Bayer Avenue.

BLODGETT, GEORGE R. (M) engineer, research, Moto Meter Gauge & Equipment Corp., *Toledo, Ohio;* (mail) 857 West Grove Place.

BOTTOMLEY, HERBERT EDWARD (F M) engineer, works manager, Brookes Brothers White Rose Garage, East Parade, *Rhyl, North Wales.*

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YOUNG, RAYMOND W. (M) executive, Wright Aeronautical Corp., Paterson, N. J.; (mail) Apartment 6-32 Abbott Court South, *Fairlawn, N. J.*

Applicants for Membership

The applications for membership received between June 16 and July 15, 1931, are listed below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

ARMSTRONG, J. H., president, C. A. S. Engineering Co., *Detroit.*

BARRIE, JOHN G., instructor in mechanical engineering, New York University, *New York City.*

BAUER, M. H., director, Fertigung, G. M. B. H., *Berlin, Germany.*

BROMBACHER, WILLIAM GEORGE, chief aeronautical instruments section, Bureau of Standards, *City of Washington.*

CAMPBELL, DONALD W., development engineer, Illinois Tool Works, *Chicago.*

COVINGTON, WILLIAM A., air mechanic, first class, United States Army Air Corps, *Randolph Field, Texas.*

DE KUZMIK, PAUL, divisional engineer, Pan American Airways, Inc., *New York City.*

GILMORE, CAPT. A. F., War Department, Camp Holabird Quartermasters Depot, *Baltimore.*

HAIDAR, FAISAL, field representative for Turkey, General Motors Near East S/A, *Alexandria, Egypt.*

HALSEY, MAXWELL NICOLL, traffic engineer, National Bureau of Casualty and Surety Underwriters, *New York City.*

HARRAH, CLAYTON C., mechanical engineer, National Standard Co., *Niles, Mich.*

HISSIN, G. N., engineer, Amtorg Trading Co., *New York City.*

JONES, THOMAS M., vice-president and sales manager, Cedar Rapids Engineering Co., *Cedar Rapids, Iowa.*

KEARNEY, LAWRENCE J., in charge of engineering of templets, Fisher Body Corp., *Detroit.*

KELLER, HUGH EDWARD, associate professor of mechanical engineering, University of Michigan, *Ann Arbor, Mich.*

KENKITI, SAKAKI, assistant designer, Tokyo Gas & Electric Engineering Co., *Tokyo, Japan.*

KRONPRINZ AKTIENGESELLSCHAFT FUR METALLINDUSTRIE, *Ohligs, Rheinland, Germany.*

MAEDA, RIICHI, assistant professor of mechanical engineering, Osaka University of Engineering, *Osaka, Japan.*

MCINTOSH, LYMAN, manager, production and automotive sales, Western Metal Specialty Co., *Milwaukee.*

ROSSINI, GUY A., automotive mechanic, Northvale Airplane & Motor Co., *Northvale, N. J.*

SCHRODT, PHILIP JOSEPH, mechanical superintendent, B. C. Motor Transportation Co., *Vancouver, B. C., Canada.*

SMITH, EDWIN C., body-layout draftsman, Pierce-Arrow Motor Car Co., *Buffalo.*

SUNNEN, JOSEPH, president, Sunnen Products Co., *St. Louis.*

STADIG, JOHN M., president and chief engineer, Stadig Aeronautical Corp., *Springfield, Mass.*

TRINIDAD LEASEHOLDS, LTD., Point-a-Pierre, *Trinidad, British West Indies.*

WHITEHOUSE, IRVING, engineering representative, Lord Mfg. Co., *Erie, Pa.*

WYATT, LUCIAN H., experimental engineer, A. C. Spark Plug Co., *Flint, Mich.*

Canadians Hold Golf Outing

DAMPENED but not disheartened by intermittent thunderstorms, 80 to 90 members and friends of the Canadian Section met for their summer outing at the Scarborough Golf and Country Club, Toronto, on Friday, July 17. They were welcomed by A. S. McArthur, Chairman of the Section, and the Reception Committee.

It was reported after the game that, though the majority finished the course, some failed to negotiate the 18 holes, and it was a matter for debate whether this was due to the weather or the ministrations of the Reception Committee.

An excellent supper was provided in the club house and each player received a prize. Tom Birkett, of the motor-vehicle branch of the Ontario Highways Department, won first prize, and R. M. Smith, Deputy Minister of Highways for Ontario, came second.

Among the guests present were D. R. Grossman, president of the Studebaker Corp. of Canada; H. A. Brown, vice-president and general manager of General Motors of Canada; John B. Mansfield, president of the Chrysler Corp. of Canada; Roy Kirby, president of Durant Motors of Canada; and L. Besaw, vice-president of the Firestone Tire & Rubber Co.

Time To Put Ideas to Use

"FOR YEARS we have been copying so faithfully that there has been nothing to argue about," quoth a speaker at a Section meeting. Members of the audience immediately started to *argue*—about thermostatic carbureter control; heating, cooling and ventilating; methods for keeping frost and ice from the windshield; independently sprung wheels; better brakes; automatic transmissions; stiffer bodies and frames; solid-injection engines; rear-mounted engines; two-cycle engines; superchargers; raindrop bodies. The party was rudely broken up by a member who remarked, "Some day, somebody's going to stop arguing and come out with a few of these ideas."

Notes and Reviews

AIRCRAFT

Full-Scale Tests of Metal Propellers at High Tip Speeds. By Donald H. Wood. Report No. 375. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 22 pp., illustrated. [A-1]

This report describes tests of 10 full-scale metal propellers of several thickness-ratios at various tip-speeds up to 1350 ft. per sec. The tests were made in the propeller-research tunnel at Langley Field, Va.

The results indicate no loss of efficiency up to tip speeds of approximately 1000 ft. per sec. Above this speed the loss is at a rate of about 10 per cent per 100-ft.-per-sec. increase relative to the efficiency at the lower speeds for propellers of pitch-diameter ratios of 0.3 to 0.4. Propellers having sections of small thickness-ratio can be run at slightly higher speeds than thick ones before beginning to lose efficiency.

Comparison of Full-Scale Propellers Having R.A.F.-6 and Clark-Y Airfoil Sections. By High B. Freeman. Report No. 378. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 20 pp., illustrated. [A-1]

In this report the efficiencies of two series of propellers having two types of blade section are compared. Six full-scale propellers were used, three having R.A.F.-6 and three Clark-Y airfoil sections with thickness/chord ratios of 0.06, 0.08 and 0.10. The propellers were tested at five pitch-settings covering the range ordinarily used in practice. These tests were conducted in the propeller-research tunnel.

The propellers having the Clark-Y sections gave the highest peak efficiency at the low pitch-settings. At the higher pitch-settings, the propellers with the R.A.F.-6 sections gave about the same maximum efficiency as the Clark-Y propellers and were more efficient for the conditions of climb and take-off.

Static, Drop and Flight Tests on Musselman-Type Air-wheels. By William C. Peck and Albert P. Beard. Report No. 381. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 20 pp., illustrated. [A-1]

This investigation was conducted at the Langley Memorial Aeronautical Laboratory during the period from January to July, 1930, for the purpose of obtaining quantitative information on the shock-reducing and energy-dissipating qualities of a set of 30 x 13-6 Musselman type air-wheels. The static tests were made with inflation pressures of approximately 0, 5, 10, 15, 20 and 25 lb. per sq. in. and loadings up to 9600 lb. The drop tests were made with inflation pressures of approximately 5, 10, 15, 20 and 25 lb. per sq. in. and loadings of 1840, 2440, 3050 and 3585 lb. The flight tests were made with a VE-7 airplane weighing 2153 lb., with the tires inflated to 5, 10 and 15 lb. per sq. in. The landing-gears used in conjunction with the air-wheels were virtually rigid structures.

The results indicate that a shock-reducing and energy-dissipating mechanism should be used in conjunction with air-wheels.

These items, which are prepared by the Research Department, give brief descriptions of technical books and articles on automotive subjects. As a rule, no attempt is made to give an exhaustive review, the purpose being to indicate what of special interest to the automotive industry has been published.

The letters and numbers in brackets following the titles classify the articles into the following divisions and subdivisions: *Divisions*—A, Aircraft; B, Body; C, Chassis Parts; D, Education; E, Engines; F, Highways; G, Material; H. Miscellaneous; I, Motorboat; J, Motorcoach; K, Motor-Truck; L, Passenger Car; M, Tractor. *Subdivisions*—1, Design and Research; 2, Maintenance and Service; 3. Miscellaneous; 4, Operation; 5, Production; 6, Sales.

Landing Impact of Seaplanes. By Wilhelm Pabst. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, January 14, 1931, vol. 22, no. 1; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 624; 29 pp., 28 figs. [A-1]

Effect of Stabilizing Forces on Turbulence. By L. Prandtl. Translated from Sonderdruck aus Vorträge aus dem Gebiete der Aerodynamik und verwandter Gebiete, Aachen, 1929. Technical Memorandum No. 625; 11 pp. [A-1]

The Frictionless Flow in the Region around Two Circles. By M. Lagally. Translated from *Zeitschrift für angewandte Mathematik und Mechanik*, vol. 9, no. 4, August, 1929. Technical Memorandum No. 626; 11 pp., 3 figs. [A-1]

Airplane Landing-Gear. By Salvatore Maiorca. Translated from *L'Aerotecnica*, vol. 10, nos. 9 and 10, September-October, 1930. Technical Memorandum No. 627; 23 pp., 70 figs. [A-1]

The foregoing four Technical Memoranda were issued during June and July, 1931, by the National Advisory Committee for Aeronautics, City of Washington.

Shock-Absorbers for Aircraft Landing-Gear. By W. S. Hollyhock. Published in *The Aircraft Engineer*, supplement to *Flight*, April 24, 1931, p. 362c (27). [A-1]

The author reviews briefly the most generally used shock-absorbing media for aircraft landing-gear—namely, oil, air, rubber and springs—with their respective advantages and disadvantgaes. He concludes that the oil-and-air, or oleo-pneumatic as it is termed, is undoubtedly the best combination in every way, since it is the lightest, offers the least aerodynamic resistance, and is more durable than the others.

The article contains a detailed analysis of the design problems involved in this type of shock-absorber.

Versuche mit Flugzeugbremsen. By Franz Michael. Published in *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, May 28, p. 302, and June 15, 1931, p. 338. [A-1]

This article, which is a publication of the German institute for aeronautical research, surveys the subject of wheel brakes for aircraft. After a few general observations on the suitability, advantages and disadvantages of different brake constructions, the self-energizing features of internal-shoe brakes are treated in some detail. A mathematical analysis is made of the characteristics of various shoe arrangements, from which conclusions are drawn as to the merits of the different constructions and rules derived for brake-shoe design.

A report is then made of landing tests with brake-shoe arrangements of two types and with various brake-linings. These tests were made for the determination of four points: (*a*) the influence on braking of different tail-skid forms; (*b*) the amount of deceleration and its decrease during the stopping time, (*c*) braking moment and the effect on brake effectiveness of the ground surface and (*d*) the effectiveness of various brake-linings under different conditions of operation.

Luftfahrtforschung, Vol 7. Published by R. Oldenbourg, Munich and Berlin; 152 pp.; 280 illustrations. [A-1]

The series of pamphlets published un-

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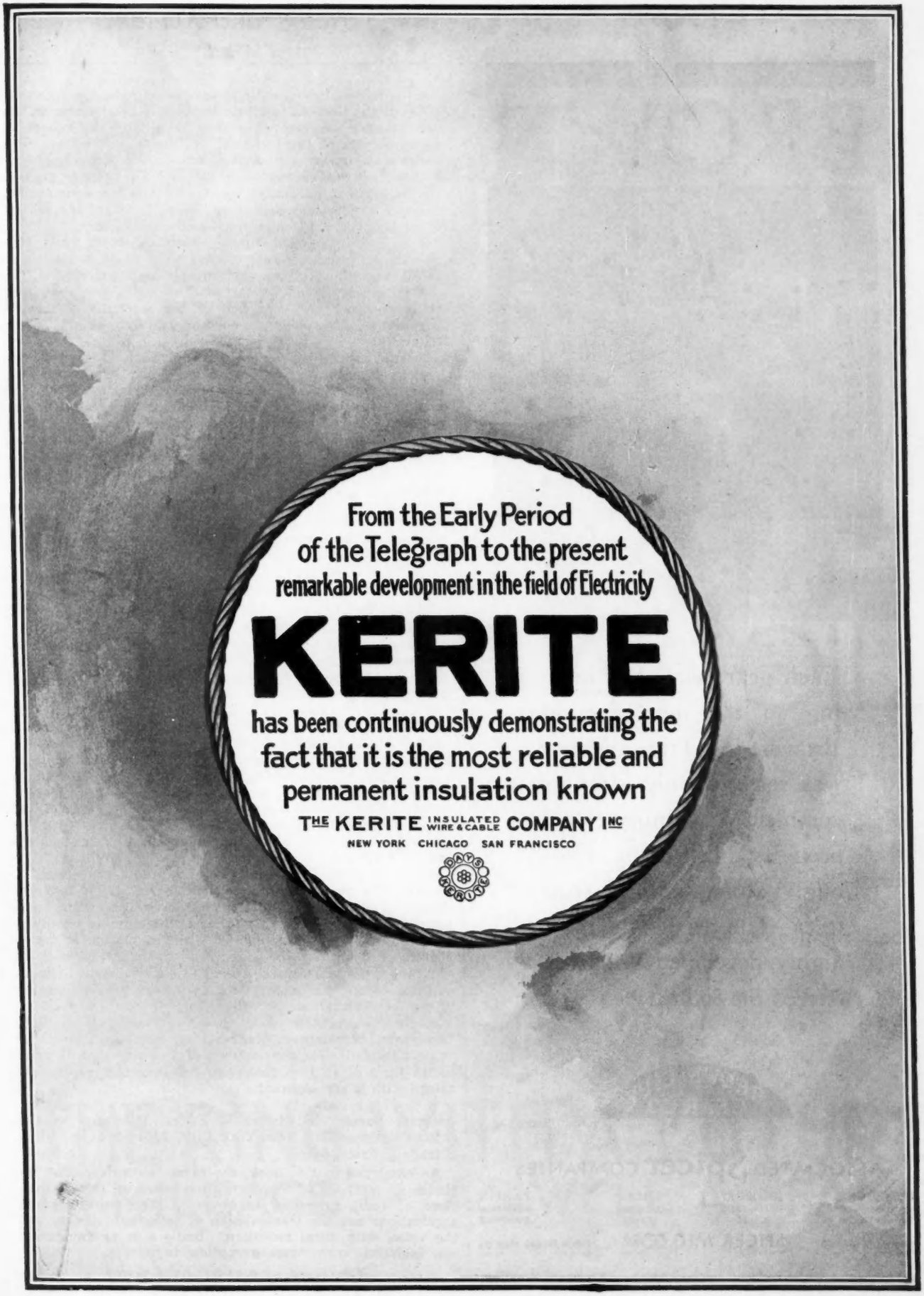
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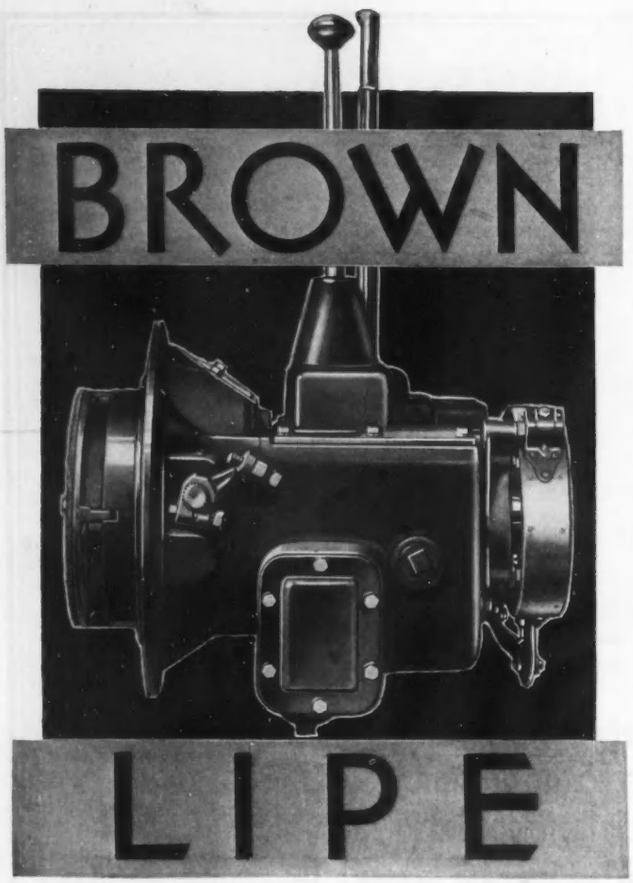

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Notes and Reviews

Continued

der the name of aeronautic research comprises the technical notes of the German institute for aeronautical research, the aerodynamic laboratory at Göttingen, and the school of aerodynamics of the technical university at Aachen. The pamphlets appear as supplements to the *Zeitschrift für Flugtechnik und Motorluftschiffahrt*. The papers present the findings of Germany's most authoritative aeronautical research institutions and assemble in one place the results of several years' investigations and experiments.

Vol. 7 consists of three parts, Part 1 of which deals with riveting in metal aircraft construction. With a wealth of detail and illustrations, current German practice is described, a variety of rivet types and methods of handling being covered. A discussion of the strength of riveted duralumin joints and a report of research on this point follow.

Wires, ropes and cables are dealt with in Part 2, the various types and methods of use being first presented. Other topics discussed are the strength of such parts, the binding of ends, splicing and their elongation, elasticity and tension in use. The durability of control cables is discussed at length, as is the corrosion of wires and wire cables and its prevention by protective coatings. Finally, the possibility of substituting some other type of structural part is considered.

Vibration of propellers is dealt with in Part 3. The theoretical treatment considers separately the effects of torsion and of bending stress. Citations of examples drawn from practice complete this section.

Luftfahrtforschung; Vol. 8. Published by R. Oldenbourg, Munich and Berlin; 154 pp.; 169 illustrations. [A-1]

This volume of technical notes of the German institute for aeronautical research, the aerodynamic laboratory at Göttingen and the school of aerodynamics of the technical university at Aachen consists of six parts each dealing with a subject of interest to aircraft designers.

Two separate investigations are included in Part 1, one on the buckling strength of streamlined rods and the other on the strength and suitability of short bolts in wooden aircraft construction and various factors affecting their usage. Wood construction is also the subject of Part 2, which reports dynamic strength-tests of various types of wood and discusses the surface protection of plywood, types of glue and their influence on the merits of plywood. The distortion of braced plates under thrust loading is dealt with in Part 3.

The interest of engine designers is appealed to in Part 4, in which is reported an extensive investigation into the causes of crankshaft failure. Many examples of fractured crankshafts are presented and, as a result of an examination of all aspects of the question, the conclusion is drawn that the remedy is to be sought, not in the substitution of different types of material, but in the development of more suitable design, particularly in the prevention or damping of torsional vibration.

Radio equipment as used on aircraft occupies the last two parts, transmitters and trailing antennas being the subject treated. The development of a new type of antenna in the form of an L is described, and favorable results obtained with it are reported.

Aircraft Radio. By Myron F. Eddy. Published by the Ronald Press Co., New York City, 1931; 284 pp., illustrated. Price, $4.50. [A-4]

As employed in this book, the term "aircraft radio" includes all methods of communication based on the applications of radio principles to aircraft. The most common applications are the transmission of telegraph signals and the voice, with aural reception. Radio aids to navigation are included, with visual-reception indicators.

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Notes and Reviews

Continued

As introductory, the author considers the development of aircraft radio, its present status in both the Government airways system and commercial transport systems, the allocation of frequencies and future applications of radio to aircraft. In following chapters he discusses the fundamentals of electricity, applications of electricity to radio, radio tubes, radio-telegraph sets, radio-telephone sets, radio aids to aerial navigation, equipping the airplane with radio, and statutes and regulations pertaining to aircraft radio. Definitions and terms and standard graphical symbols used in radio engineering are given in two appendixes.

The author, who is a retired officer of the United States Navy, was formerly instructor in aircraft radio at naval aviation ground-schools and subsequently at commercial aviation schools.

Airports—Their Location, Administration and Legal Basis. By Henry V. Hubbard, Miller McClintock and Frank B. Williams, assisted by Paul Mahoney and Howard K. Menhinick. Vol. I., Harvard City Planning Studies. Published by the Harvard University Press, Cambridge, Mass., 1930; 190 pp., illustrated. Price, $3.50. [A-4]

The authors point out that the rapid growth of air transportation in the United States has far outstripped the knowledge and experience essential to direct it efficiently. Therefore many important decisions are necessarily being made daily without waiting for the compilation of sufficient data or the training of enough experts.

In 1929 Harvard University established the Graduate School of City Planning, with research as a principal function. In this, the first of the series of studies undertaken, the School has endeavored to obtain a fair general view of the situation which obtains with regard to airports, by means of a first-hand study of 67 cities and 85 typical airports in 32 States in the United States and by a careful analysis of the data so obtained with the cooperation of many well-informed persons considering the subject from many different angles.

The purpose of the three reports that make up this volume as stated by the authors, is to suggest as far as possible how those responsible for the airports can arrive at reasoned and reasonable decisions regarding them, in the light of what others have done and of broad consideration of city planning, municipal administration and law.

Deck Flying. By W. R. D. Acland. Published in *The Journal of the Royal Aeronautical Society*, May, 1931, p. 372. [A-4]

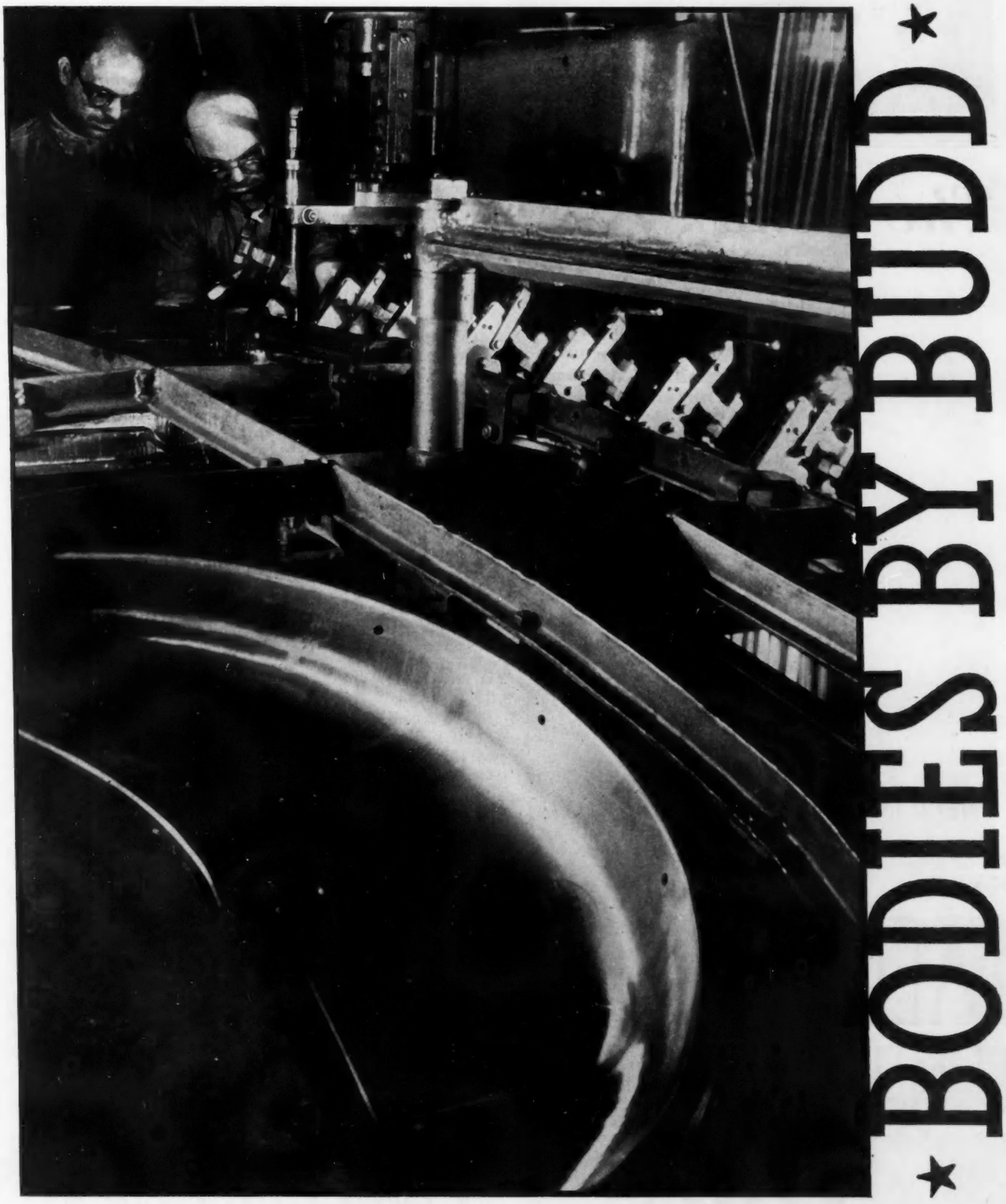
Since this constitutes the first lecture on deck flying presented before the Royal Aeronautical Society, the author traces briefly the development of the modern aircraft carrier from the improvised auxiliaries commissioned to meet war exigencies. The writer concludes with remarks upon the special characteristics required in an aircraft to be used successfully for deck flying.

Characteristics of Airplane Antennas for Radio Range-Beacon Reception. By H. Diamond and G. L. Davies. Published in the *Bureau of Standards Journal of Research*, May, 1931, p. 901. [A-4]

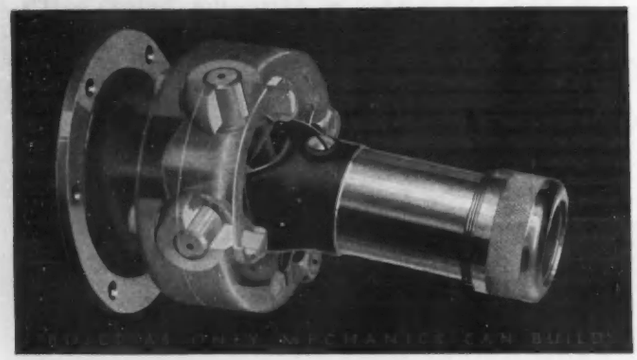
In this paper the authors give the results of an investigation on the characteristics of airplane receiving antennas to determine whether an antenna arrangement could be devised which would have all the desirable electrical properties of the vertical-pole antenna and yet be free from the mechanical difficulties encountered in the use of this type. The antennas studied include the inclined antenna with both forward and backward inclination, the horizontal dipole antenna, the horizontal L antenna, the horizontal V antenna, the inclined V antenna, the symmetrical transverse T antenna and the symmetrical longitudinal T antenna.

(*Continued on next left-hand page*)

Automobiles are so good to-day that the importance of small body noises or other minor imperfections is bound to be magnified. In the one-piece body Budd safeguards the littlest things. For example, a jig, holding the whole side of a body, has been devised to insure the faultless spot welding of rain gutters to the body. Such attention to seemingly trivial details is one of the reasons why Budd one-piece bodies are uniformly free from small flaws . . . and permanently quiet.



Originators of the All-Steel Body. Used to-day by manufacturers in the United States, Great Britain, France and Germany.



The trend . . . . .

is high speed . . . high velocity . . . high powered transportation brings to the attention of car owners and car manufacturers alike, the necessity of thorough lubrication of the moving parts. Essential to the correct and dependable transmission of the increased power is the design, construction and operation of the Universal Joint assembly.

Mechanics Universal Joints are engineered to modern high-duty requirements. They are "Oil Lubricated—Oil Tight." Oil has been proven the most effective lubricant for Universal Joints . . . Mechanics retain the Oil. Specify Mechanics Universal Joints on modern high-duty cars and trucks.

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MECHANICS UNIVERSAL JOINT

Notes and Reviews

Continued

A theoretical treatment is given which enables the voltage induced by a radio range-beacon transmitting station to be calculated for any receiving antenna in space. This theoretical analysis is used to determine the received voltage, course error and localizing effect for each of the antenna types studied. An experimental study was also made to check the theoretical analysis. The results obtained by experiment check very well with the theoretical predictions for each type of antenna. The symmetrical transverse and the symmetrical longitudinal T antenna, with the vertical lead-in portions, are both found to fulfill the desired requirements. Neither of these antennas shows any course errors and they give the same received voltage as the vertical-pole antenna having much greater actual height, thus reducing the mechanical troubles caused by vibration and ice formation. An appendix gives the mathematical derivation of the equation used as a starting point for the theoretical analysis.

BODY

Body Noises Being Reduced To Meet Demand of Owners. By Joseph Geschelin. Published in *Automotive Industries*, April 4, 1931, p. 542. [B-1]

Because the buying public has grown to expect freedom from noise in automobiles, the body maker must be keenly alive to the demands made on his product. Although, as Mr. Geschelin points out, no really obscure problems are involved, the situation is complicated by the fact that not only must the body structure be made silent but it must also be sound-proofed and insulated from outside effects that tend to filter in.

With the cooperation of a number of the outstanding body manufacturers, the author presents some of the latest slants concerning the sources of objectional noises and approved methods for eliminating them, and discusses some of the recently developed materials specially designd for this work. The study appears in two parts, the first dealing with the fundamental aspects of the problem, while the second, published in the April 18, 1931, issue of *Automotive Industries*, p. 620, describes actual practice in some of the body plants.

CHASSIS

A Novel Transmission. Published in *The Autocar*, May 1, 1931, p. 792. [C-1]

The Salerni automatic transmission, a four-speed gear-set of epicyclic type, is described briefly and credited with certain features and performance that make it an outstanding contribution to the field of automatic gearshifting devices. All the ratios, including reverse, are selected automatically, and, according to the author, without shock, on the movement of a short lever conveniently located on the steering-wheel. The writer also claims that the design assures a correct gear-change, instead of allowing the driver to effect an incorrect change, without damage, as is the case in some other automatic devices.

The object sought in the Salerni transmission is to provide a transmission which gives a positive drive in all circumstances, each gear being selected by the engagement of dogs. Herein is said to lie the ingenuity of the gear, for normally such a method of gear engagement needs skill and judgment in the estimating of relative speeds if jerk and snatch are to be avoided. The Salerni is so arranged that, at the moment of engagement, both the revolving masses are always stationary relative to each other.

Trends in the Transmission. By Henry E. Merritt. Published in *The Automobile Engineer*, March, 1931, p. 121. [C-1]

The author points out that the directions in which improvement in riding comfort is being sought through trans-

(*Continued on next left-hand page*)

A NEW WHEEL BY BUDD

Motorists who prefer the artillery type of wheel can now have that type in the material that rapidly is becoming universal in wheels—STEEL!

For Budd—after testing, and after experimenting for years—now offers to the automotive world the first successful steel artillery wheel.

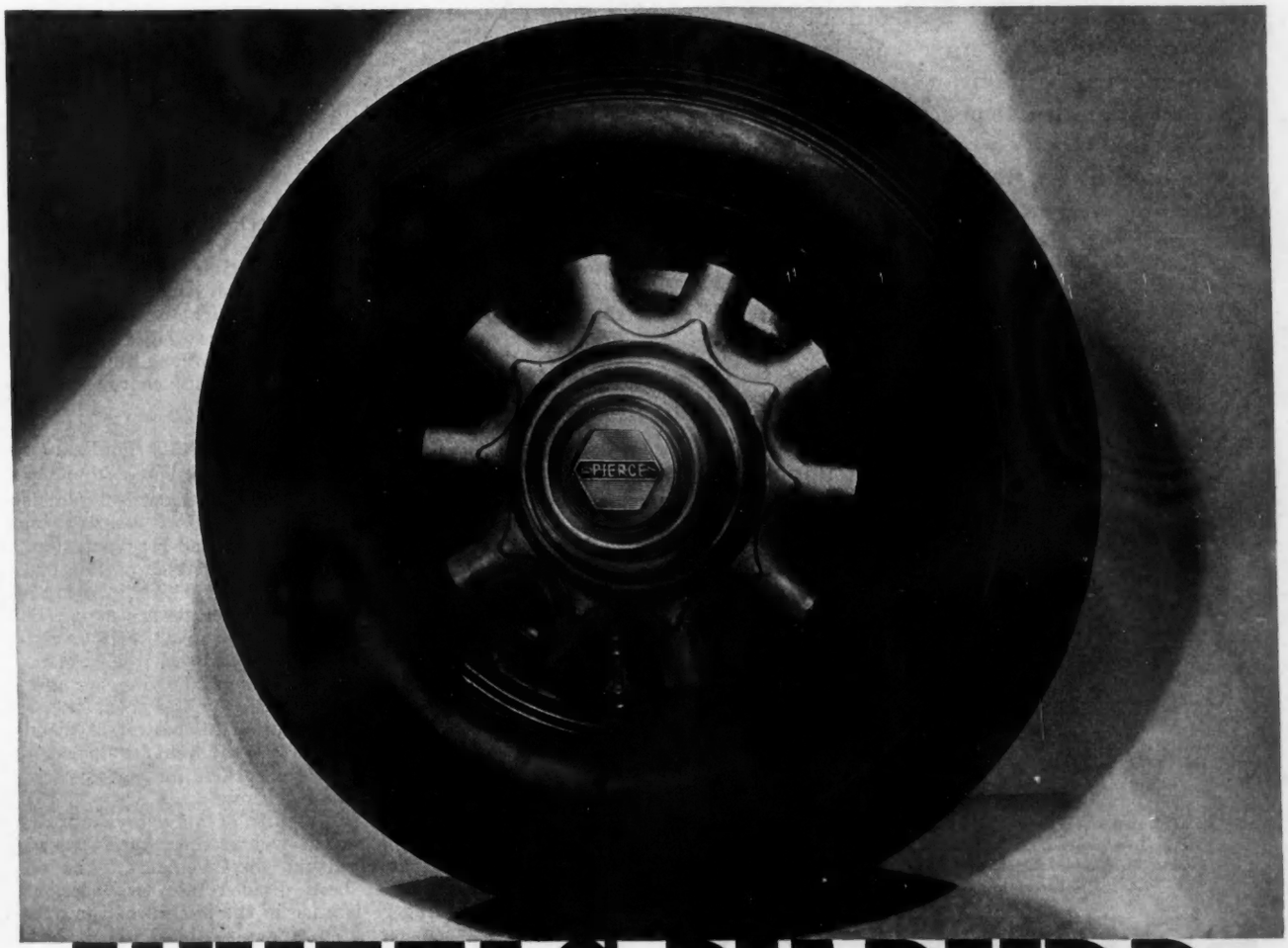
Beautiful? Look at it. But more. It is six pounds lighter than an equivalent wood wheel. In lateral tests, it proves to be four to five times stronger. And it permits better decoration at less cost.

This wheel is made in both low-carbon steel, and in stainless steel. In low-carbon steel, it can be given a natural wood finish—or can be finished in lacquer the same as the body. And finishing is a matter of hours—instead of the days necessary with wood.

In stainless steel, it harmonizes with any color scheme—contributes brilliance and richness.

This new Budd-Michelin wheel is displayed at the Budd plants in Philadelphia and Detroit. We'd like you to see it. We'd like to tell you more about it.

Stainless Steel Wheel as Designed for Pierce Arrow



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BETHLEHEM ALLOY STEELS

Notes and Reviews

Continued

mission design are: (*a*) reduction of noise, (*b*) ease of control and (*c*) improvement of suspension.

Mr. Merrit comments on the so-called "silent third gear," which he prefers to call "a constant-mesh third," and discusses the possibility of departing from straight spur gears for the less noisy single-helical, double-helical and internal gears, citing examples of the application of these types.

Under the heading Ease of Control, the author considers the planetary gear and the isolating coupling or free-wheel.

Modifications in transmission design which tend toward an improvement in suspension include: (*a*) worm, or to a less extent hypoid, drive with unsprung axle; (*b*) the same set-up but with independently-sprung rear wheels; (*c*) front drive with unsprung front axle; and (*d*) the same set-up but with independently-sprung wheels.

No general conclusions are drawn by the author from his summary, but he raises the question, Why, with so many different directions for improvement, do the majority of makes of cars remain so much alike?

Electric Lighting Equipment. By Harry Cousins. Published in *The Automobile Engineer*, March, 1931, p. 100. [C-1]

This article is a consideration of the lighting requirements of passenger-cars and motorcoaches in service. Batteries, dynamos and electrical systems are treated in relation to the increasing demand for more adequate interior lighting facilities in motorcoaches.

Brake-Shoe Design. By Henry E. Merritt. Published in *The Automobile Engineer*, May, 1931, p. 183. [C-1]

The author sets forth three main objects which should be considered in brake design; namely, to produce the maximum braking torque for a given size of drum, to obtain this braking torque with the minimum operating effort, and to secure the maximum service from the lining material. In this article is outlined a technical scheme on which the design of brakes may logically be based, in place of the hit-and-miss methods that seem sometimes to be used.

The following conclusions are also drawn as a result of the study: (*a*) that customary brakes are open to improvement as regards the use made of the available surface of the drum, (*b*) that shoes should not be too long and (*c*) that self-energized brakes are likely to be treacherous if the coefficient of friction drops.

Rigid Six-Wheeled Vehicles. By W. Steeds. Published in *The Automobile Engineer*, May, 1931, p. 172. [C-1]

The author explains that in most rigid six-wheel vehicles the front pair of wheels is used solely for steering and weight-carrying purposes. The middle and rear pairs only are driving wheels and the springing systems of these vehicles are always arranged so that, when the vehicles are at rest, the loads carried by the driving wheels are equal. In many designs, however, this equality is upset as soon as a driving torque is applied to the drive wheels, the tendency usually being to increase the load carried by the rear driving axle and to decrease that carried by the front one, in extreme cases to zero. This alteration in the weight distribution is not of very great importance in vehicles operating on good roads but may be a very serious matter in cross-country vehicles operating on soft ground.

The present notes give the results of an analysis of the effect of torque reaction on the weight distribution in the most common types of rigid six-wheel vehicles. The analysis for each type has been divided into two sections. In the first the rolling resistance to the motion of the driving wheels has been neglected, and also those wheels have been assumed to be revolving at a uniform speed; in the second section the whole of the torque applied to the driving wheels has been taken to be used in overcoming rolling resistance to the motion of the driving wheels or in accelerat-

(*Continued on next left-hand page*)

MINIMUM END CLEARANCE

The Thompson Eccentric Tie Rod meets every requirement of four-wheel brakes and balloon tires. Its compact construction requires only a minimum of end clearance. Additional advantages are: positive safety, light weight, easy steering, ample lubrication, sealed socket, quick assembly and servicing, reasonable cost — *and extreme mechanical simplicity* (*only four parts within the socket*).

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Notes and Reviews

Continued

ing them. The analytical results are followed in each case by numerical results to show the magnitude of the alterations in the axle loads. The dimensions and data on which these numerical results are based are the same for all the types considered, so the results will serve as a comparison between the types. To illustrate the method of analysis, one example has been given in full.

The Design of Inner Tubes. T. K. Sherwood and T. M. Knowland. Published in *India Rubber World*, April 1931, p. 53. [C-1]

The use of rubber in the construction of hollow inflatable articles calls for special treatment in the design as well as in the methods employed in fabrication, the authors declare. In the case of perhaps the most important article in this class, the inner tube, much has been done in compounding, in production methods and in technical control of the product, while the design has been open to much empiricism, they contend.

In designing a tube for a given tire, four important variables are under the control of the designer; namely, tube diameter, tube length, gage of uncured stock and quality of compound.

The authors discuss these factors and give a mathematical analysis of the stresses and particularly the strains in inflated inner tubes, with notes explaining the special applications of the method. Such an understanding, it is their belief, is absolutely essential if tube design is to be put on a rational basis.

ENGINES

Basic Requirements of Fuel-Injection Nozzles for Quiescent Combustion Chambers. By J. A. Spanogle and H. H. Foster. Technical Note No. 382. Published by the National Advisory Committee for Aeronautics, City of Washington, June, 1931; 6 pp., 7 figs. [E-1]

This report presents test results obtained at the Langley Memorial Aeronautical Laboratory in an investigation of the performance of a single-cylinder high-speed compression-ignition test engine when using multiple-orifice fuel-injection valve nozzles in which the number and direction of the orifices were varied independently. The orifice sizes generally conformed to the principle that the orifice area should be proportional to the volume of air served by the orifice.

The test results indicate that it is unnecessary to follow the proportional principle to extremes and that complication of nozzle design does not give a commensurate increase in performance. The optimum angle between orifice axes was judged to be 25 deg. for the conditions in this quiescent combustion-chamber, but this value is not critical.

Effect of High Air Velocities on the Distribution and Penetration of a Fuel Spray. By A. M. Rothrock. Technical Note No. 376; 10 pp., 12 figs. [E-1]

A Suggested Method for Measuring Turbulence. By C. Fayette Taylor. Technical Note No. 380; 7 pp. 4 figs.

The foregoing two Technical Notes were issued during May and June 1931, by the National Advisory Committee for Aeronautics, City of Washington.

Effect of Ring-Type Engine Cowls on Model of Douglas XO-14. Five-Foot Wind-Tunnel Test No. 35. Air Corps Technical Report No. 3353; 6 pp. with tables and charts. [E-1]

The foregoing Air Corps Information Circular was published by the Chief of the Air Corps, City of Washington, April 1, 1931.

(*Continued on next left-hand page*)

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TOUGH-Aluminum Alloy Pistons face a firing squad hundreds of times a minute and *Live*

"Load"—"Ready"—"Aim"—"Fire"—Like a command to a firing squad, your foot on the throttle gives the signal. A wall of exploding flame hits the pistons—but Lynite Pistons are not made to be "killed in action." They are just naturally tough.

But mere toughness is not enough. Lynite Pistons are made of light, strong alloys of Alcoa Aluminum, which weigh only ½ as much as old-fashioned piston material, and conduct heat many times faster. There lies the difference—*such a difference* that manufacturers, placing performance and your operating economy ahead of price, deliberately pay more for aluminum alloy pistons to give you advantages like these: longer piston life; cooler engines; less carbon; reduced vibration; less wear on bearings and cylinders.

Buy cars equipped with aluminum alloy pistons and you get more performance for your automobile dollar. When replacing pistons in your present car be sure to specify Lynite Pistons made of the light, strong alloys of Alcoa Aluminum. ALUMINUM COMPANY of AMERICA, 2497 Oliver Building, PITTSBURGH, PENNA.

What a proving ground! Nearly 2 Billion miles of driving each year by owners of these cars* equipped with aluminum alloy pistons.

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*From Automotive Industries

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STORAGE BATTERIES

Notes and Reviews

Continued

Automobile Fuel-Line Temperatures and Vapor Lock. By Oscar C. Bridgeman. Paper presented at the mid-year meeting of the Division of Refining, American Petroleum Institute, St. Louis, April 15, 1931. [E-1]

A summary is given of the work of the last two years on the problem of vapor lock, under the direction of the Cooperative Fuel-Research Steering Committee, which has led to a simple relation between vapor pressure by a commonly used method and the temperature at which vapor lock occurs. Fuel-line-temperature data obtained in 27 cars of recent model are interpreted in terms of permissible vapor pressure, and the author points out that large differences in permissible vapor pressure exist in various makes of car. Suggestions are made regarding improvements in design of fuel-feed systems tending to lower fuel temperatures, and the effect of certain changes is illustrated quantitatively.

Bearing Design in the Light of Oil-Film Pressure Investigations. By L. J. Bradford. Paper presented at the Lubrication Engineering Meeting, Fifth Oil Power Conference, State College, Pa., May 22, 1931. [E-1]

Four years ago a machine specially designed for the investigation of oil-film pressures in a complete bearing lubricated from the end was loaned to the Pennsylvania State College. Since that time studies have gone forward continuously, and during the last two years the work has been supported by a fellowship established by the Texas Co.

Professor Bradford draws the following rules for bearing design from a study of the pressure distribution:

(1) Keep the bearing surface uninterrupted in the region of maximum pressure.

(2) Give the bearing a plentiful supply of oil.

(3) Place oil grooves either circumferentially at the ends or in the center of the bearing, or axially on the side away from the load, or place them at right angles to the line of the load.

(4) Avoid excessively long bearings if the load is heavy.

(5) Machine both bearing and journal accurately.

(6) High supply pressures are unnecessary if the point of application is well chosen, and are useless otherwise.

The Origin and Development of Heavy-Oil Aero Engines. By D. R. Pye. Published in *The Journal of the Royal Aeronautical Society*, April, 1931, p. 266. [E-1]

This paper constitutes the first Akroyd-Stuart Memorial Lecture and is particularly concerned with tracing the parenthood, in the world of invention, of the heavy-oil aeronautic engine of the future, to decide whether a grasp of the essential principles without which an aeronautic engine could never come to birth is to be found in the ideas of Herbert Akroyd-Stuart or of Dr. Rudolf Diesel, and in one more than in the other.

The article is divided into parts covering the following phases of the subject: I, Historical; II, The Engine Problem; III, Cycles and Modes of Operation Employed; IV, Single-Cylinder Research Work; V, Practical Developments; and VI, Future Progress, together with extensive discussion and the author's reply.

Jalbert Heavy-Oil Engine Using Carbureter and Pre-Mixing Cylinder under Construction for the French Air Service. By W. F. Bradley. Published in *Automotive Industries*, April 4, 1931, p. 548. [E-1]

The use of a carbureter and a pre-mixing and compression cylinder is the feature of the six-cylinder 200-hp. Jalbert engine now under construction for the French Air Service, after experiments with a single-cylinder model.

The engine is a six-in-line of 125 × 180-mm. (4.92 × 7.09-in.) bore and stroke, which will develop 180 hp. at 1930 r.p.m It has steel cylinders on an aluminum crankcase,

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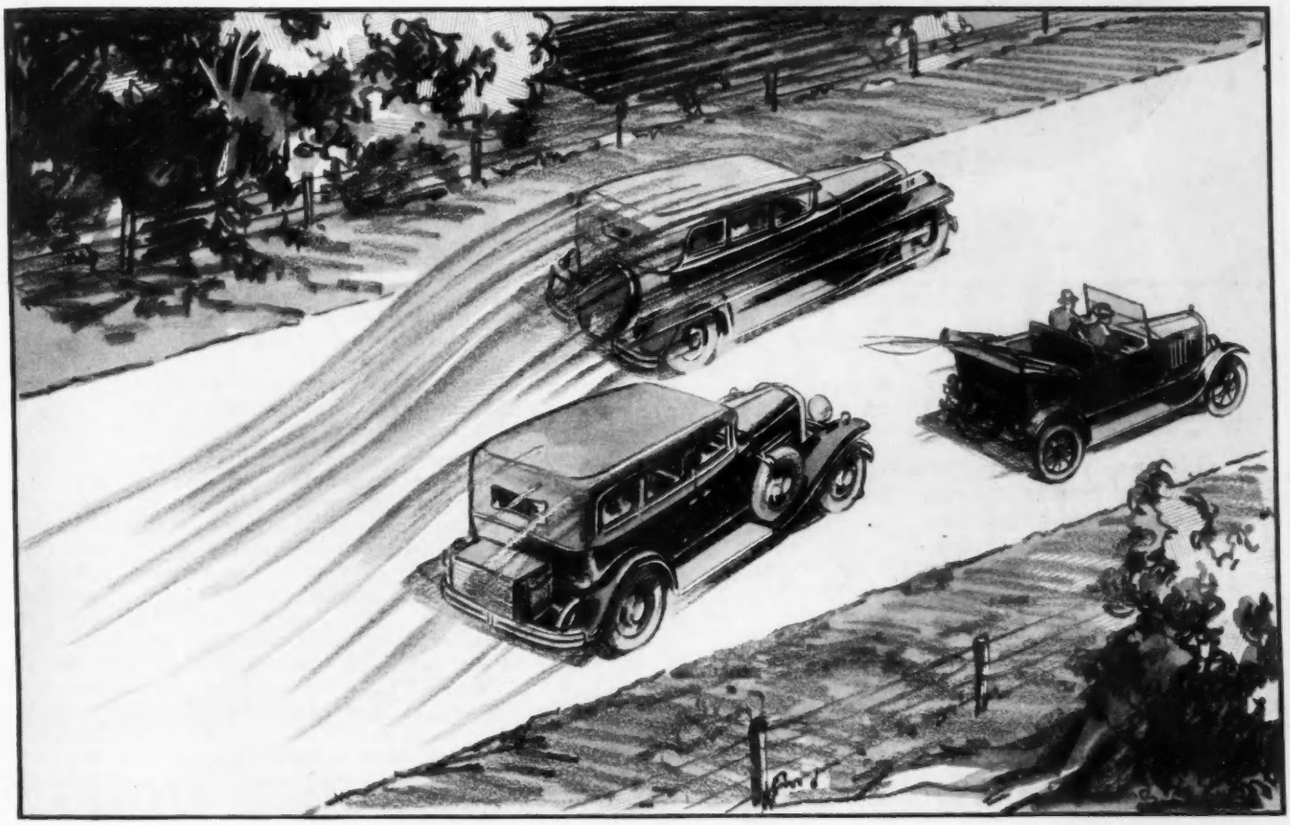

● *Safety—mental ease—physical relaxation—at today's high speeds—all demand steering that responds accurately and instantly. Ross inspires the driver with well-founded confidence in his control in any situation where safety depends on steering*

Speed is built into today's cars—to stay. For driving comfort and safety, steering must be proportionately accurate and responsive—*for the life of the car*. The Ross Roller-Mounted Cam and Lever Steering Gear is the most accurate and instantly responsive instrument of steering that has ever been put in a driver's hands. It maintains this accuracy and responsiveness throughout the life of the car—*first*, because wear has been reduced to a negligible point through the relative absence of friction; *second*, because precision adjustments built into the gear make it possible to retain the original accuracy of alignments and clearances.

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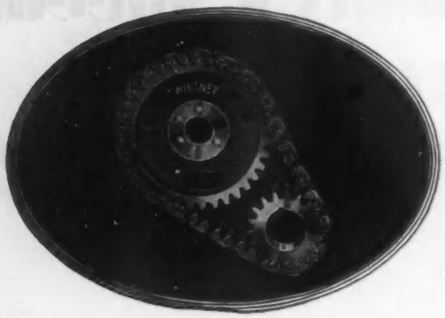

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Notes and Reviews

Continued

with sheet-steel welded-on jackets, and a seven-bearing crankshaft. Two vertical valves are mounted in the head, being operated by two separate camshafts through pushrods and rockers.

In place of the fuel-pump and injector usual on Diesel engines, the engine has a carbureter that feeds a small cylinder mounted on the head of each working cylinder. The small cylinder is fitted with a piston connected to an overhead crankshaft by means of a connecting-rod and running at one-half engine-speed. Connection is made between the fuel cylinder and the working cylinder by an automatic valve having a very small lift. The claim is made that, by reason of the small lift and quick return of the automatic valve, higher engine-speeds can be obtained than with the usual type of pump and injector. Other advantages are a completely atomized mixture and more nearly equal distribution to the cylinders than is obtainable with a pump.

The Compression-Ignition Automobile Engine. By S. W. Nixon. Published in *The Automobile Engineer*, May, 1931, p. 196. [E-1]

The so-called Diesel engine, or compression-ignition engine, has for some time excited the interest of designers as a suitable power unit for automobile purposes, if certain inherent disadvantages could be overcome. The chief disadvantage, Mr. Nixon declares, is structural weight, and the increased knowledge concerning the properties of light alloys has enabled a considerable amount of progress to be made in this direction.

In the commercial-vehicle field the requirements regarding engine weight are less exacting than in the automobile field, and Continental European manufacturers definitely lead in the former, having passed from the experimental to the production stage about two years ago. In England, development does not seem to have emerged from the experimental stage, except in one case, in which a German design is manufactured under license.

The author deals with the subject under the following headings:

(1) The compression-ignition cycle
(2) Advantages of the cycle in comparison with carbureter-type engines
(3) Disadvantages of compression-ignition engines
(4) The requirements of and some methods of fuel injection
(5) Details of some existing engines
(6) Future possibilities.

Designers Must Cool Hot-Spots in Fuel Lines To Defeat Deviltry of Vapor Lock. By Joseph Geschelin. Published in *Automotive Industries*, May 23, 1931, p. 769. [E-1]

The author presents in popular form the results of the recent research work on vapor lock and its causes, a large portion of which has been conducted at the Bureau of Standards under the direction of the Cooperative Fuel-Research Steering Committee and presentd by Dr. O. C. Bridgman in papers read before the American Petroleum Institute and The Society. Special emphasis is placed on the responsibility of the design engineer for avoiding excessive heat in the fuel line, pump and carburetr.

Photographic Flame Studies in the Gasoline Engine. By Lloyd Withrow and T. A. Boyd. Published in *Industrial and Engineering Chemistry*, May, 1931, p. 539. [E-1]

An apparatus with which, by photographic means, simultaneous flame and pressure studies have been made of individual explosions in the gasoline engine, is described. The records obtained clearly show the relation between the rates of flame travel and the resulting rates of pressure rise in knocking and in non-knocking explosions. They indicate that the phenomenon of knock in the gasoline engine, which

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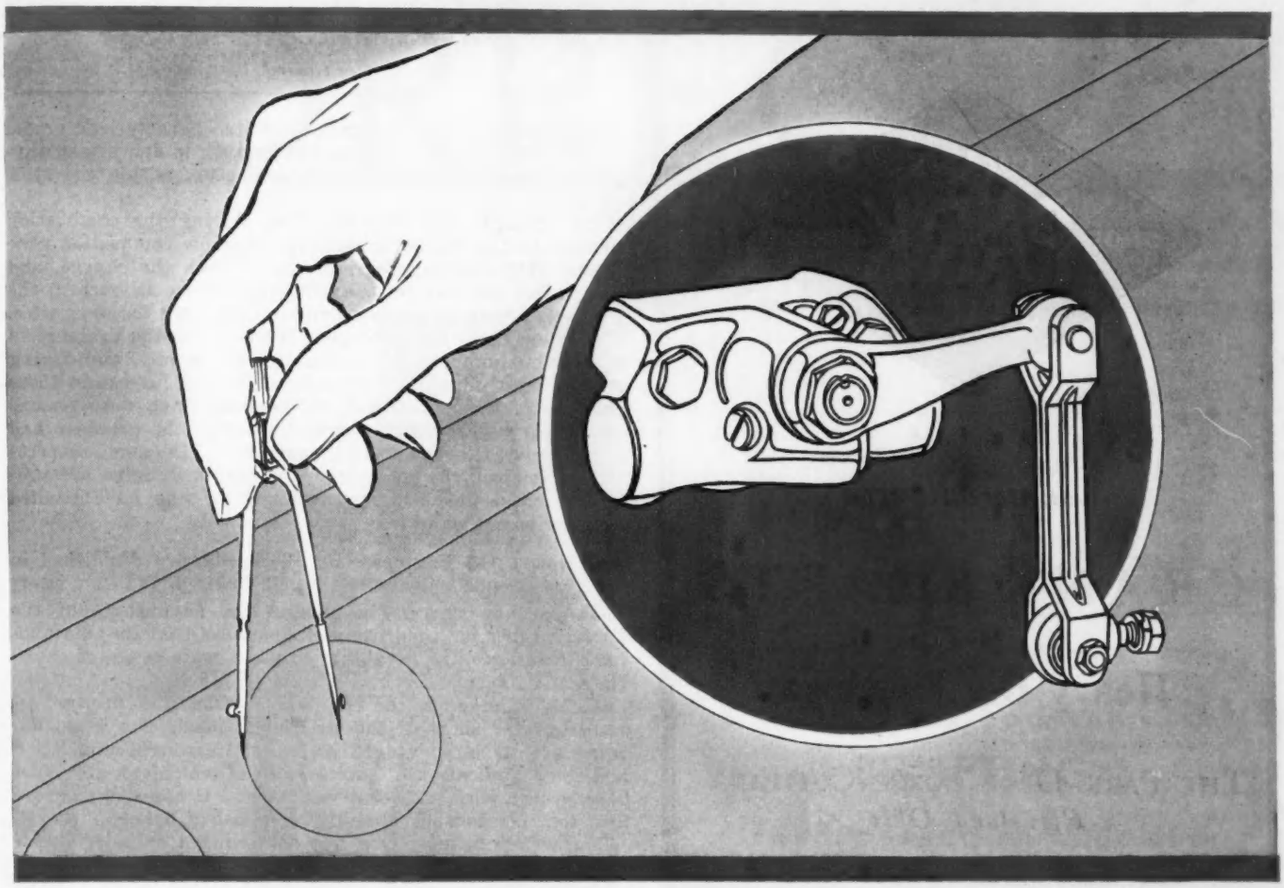

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Delco
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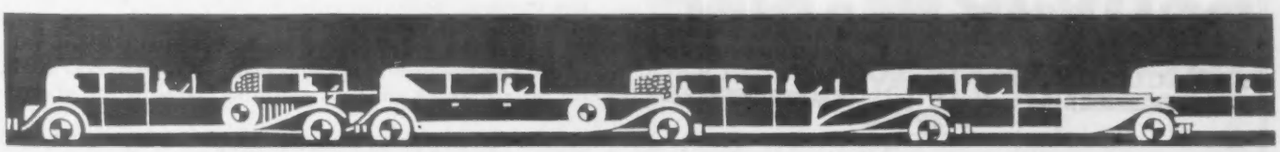

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Notes and Reviews

Continued

heretofore has been recognized by its characteristic sound and by the shape of its pressure record, is due to a many-fold increase in the rate of inflammation within the later portion of the charge.

The records also indicate that, during the combustion process in the engine, a relatively narrow combustion zone exists which moves progressively through the charge, and that, after the fuel in the combustion zone is burned, the products of combustion continue to emit light for some time. The intensity of this afterglow increases as the pressure in the combustion-chamber begins to rise rapidly, and during the period of maximum pressure it is most intense in those portions of the products of combustion which were formed in the early part of the explosion before the pressure had risen above the compression pressure. In some respects these flame records taken from the gasoline engine are similar to those obtained by investigators who have studied combustion in bombs.

Automotive Oil Engines. By P. E. Biggar. Published in *The Automobile Engineer*, April, 1931, p. 143. [E-4]

The author surveys in general the advantages of the Diesel engine for road use and concludes that its outstanding advantages are its ability to use a wide range of cheap fuels and its high thermal efficiency. He contends that the latter is inherent in the engine cycle and that present results fall far short of the theoretical ideal. Its disadvantages are its bulk, weight and cost, its rough combustion and the complication of starting, all of which can and must be improved with further development. It has still to prove itself on the score of reliability and cost of upkeep.

The writer believes that any skimping of cylinder size is very bad policy, and contends that the present-day oil engine requires an ample piston displacement for its job and justifies this large size on the ground of low fuel consumption at light loads. Disregarding for the moment the undoubted future of supercharging and the use of the two-stroke cycle, he believes that the best line of attack is to use the simple induction-turbulence type of combustion-chamber and a pump having small clearance capacity and definite cut-off combined with a valve-controlled sprayer.

MATERIAL

Progress Toward a Standard Method for Determining the Antiknock Value of Motor Fuels. By H. C. Dickinson. Paper presented at the mid-year meeting of the Division of Refining, American Petroleum Institute, St. Louis, April 15, 1931. [G-1]

In this paper Dr. Dickinson outlines briefly the history and progress of the cooperative effort to develop a universally acceptable standard method of measuring the knocking tendency of motor gasoline. Reference is made to the beginnings of research on the phenomena of detonation in England and the United States, and the inception, organization and purpose of the Detonation Subcommittee of the Cooperative Fuel-Research Steering Committee are sketched. The author concludes with a summary of the results obtained to date from the work conducted under the direction of that group.

Detonation Characteristics of Some Aliphatic Olefin Hydrocarbons. By Wheeler G. Lovell, John M. Campbell and T. A. Boyd. Published in *Industrial and Engineering Chemistry*, May, 1931, p. 555. [G-1]

The relative tendencies to knock in an engine were measured for 25 olefin hydrocarbons. These measurements were made, not on the hydrocarbons alone, but in admixture with gasoline, and the results are expressed on a molecular basis, using the antiknock effect of anilin as the standard of comparison.

Definite relationships between molecular structure and tendency to knock have been found for these compounds.

(*Continued on next left-hand page*)

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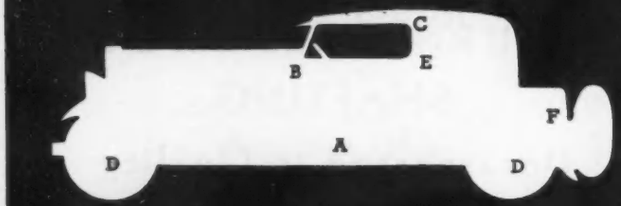

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Notes and Reviews

Continued

Endurance and Other Properties at Low Temperatures of Some Alloys for Aircraft Use. By H. W. Russell and W. A. Welcker, Jr. Technical Note No. 381. Published by the National Advisory Committee for Aeronautics, City of Washington, June, 1931; 16 pp., 20 figs. [G-1]

The low-temperature endurance properties of materials for aircraft construction are not well known. To determine them, apparatus for testing endurance at —40 deg. cent. (—40 deg. fahr.) has been devised.

The endurance properties of monel metal, low-carbon stainless steel, "18 and 8," 3½-per cent Ni steel and chromium-molybdenum steel have been determined at —40 deg. cent. and at room temperature (about 20 deg. cent.). Tensile, impact and hardness tests of these materials were also made at various temperatures. The results show an increase in endurance limit, tensile strength and hardness with decreased temperature. Impact strength is, in general, decreased, but of all the alloys tested, only one, low-carbon stainless steel, gives less than 15 ft-lb. Charpy impact test at —40 deg. cent.

X-Rays in the Steel Industry. By H. H. Lester. Published in the *Journal of the Franklin Institute*, May, 1931, p. 567. [G-1]

The development and present status of x-ray diffraction apparatus is reviewed and the instruments now in use are described with the aid of diagrams and photographs. The writer stresses the importance of the x-ray to the steel maker and user. The subject matter is presented in a non-technical manner.

Selecting and Hardening High-Speed Steel. By Alfred Heller. Published in *American Machinist*, April 23, 1931, p. 635. [G-5]

This is the first of a series of three articles in which are discussed the hardening characteristics of five representative classes of high-speed steels and the roughness of these steels when subjected to a range of temperatures and periods of soaking. The last article of the series develops the technique for tempering these steels and gives practical information on their selection for various uses.

The second and third articles in the series appear in the April 30 and May 7, 1931, issues respectively of *American Machinist*.

Experiments in Metal Polishing. By Edwin M. Baker and George E. Holbrook. Published in *American Machinist*, May 14, 1931, p. 749. [G-5]

In this article the authors report the effects, as determined by research, of pressure, grain size and glue concentration upon the speed of cutting and efficiency of flexible wheels when polishing steel preparatory to plating.

MOTORBOAT

Aluminum-Alloy Motor Launch. Published in *Engineering*, April 24, 1931, p. 542. [I-1]

There has been considerable speculation concerning the use of some material other than steel or wood for the construction of small boats and launches with a view toward securing greater lightness and freedom from corrosion. Considerable interest therefore attaches to the launch built by the Birmingham Aluminium Casting Co., Ltd., as it is constructed throughout of aluminum alloy, known as Birmabright.

This material is a high-percentage aluminum alloy containing some magnesium but very little silicon. It is said to have high corrosion-resisting properties and has been in use for some years in the form of castings, rods and bars, and seamless-drawn tubing for a variety of purposes, es-

(*Concluded on next left-hand page*)

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EVERY TIME you telephone you share the benefits of a nation-wide communication system using eighty million miles of wire and employing four hundred thousand people. It represents a plant investment of more than four thousand million dollars, yet you can use a part of it for as little as five cents . . . for considerably less on a monthly service basis.

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The growth of the Bell System through the past fifty-five years and the constant improvement in service may well be called one of the great achievements of this country. Greater even than that are the policies, improvements and economies that make this service possible at such low cost.

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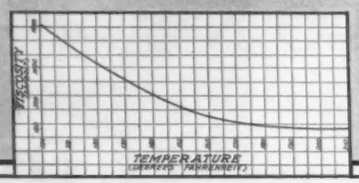

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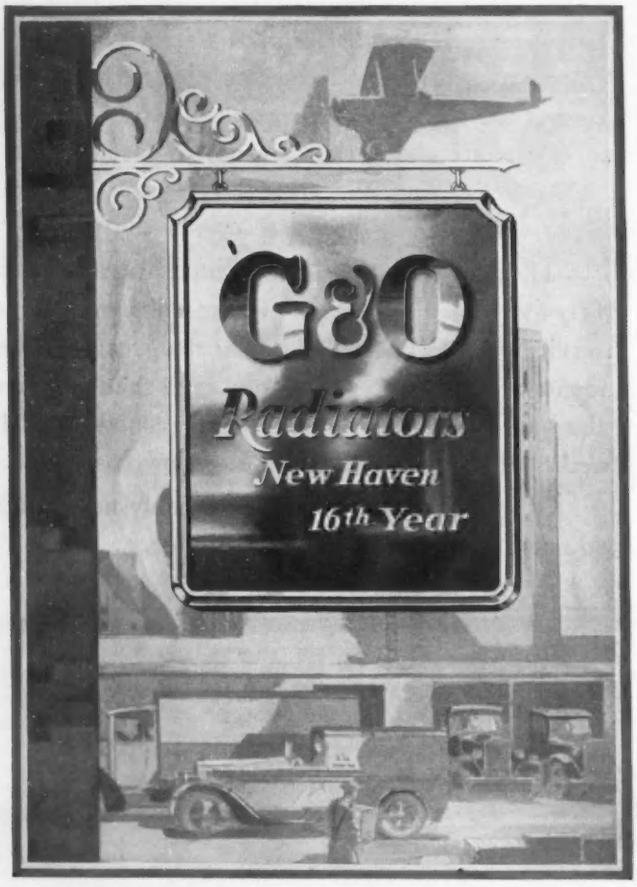

Notes and Reviews

Concluded

pecially in the chemical industry. It can be welded autogenously in the sheet, extruded and drawn forms, and its machining properties are good.

Specifications and details of the launch, named Miss Birmabright, are included in the article.

MOTORCOACH

Impact Reactions Developed by a Modern Motor Bus. By James A. Buchanan. Published in *Public Roads*, April, 1931, p. 21. **[J-1]**

One of the most important trends in the use of highways today is that toward higher vehicle-speeds, particularly with the heavier wheel-loads, declares Mr. Buchanan in the introduction to this report of the impact reactions produced on pavements by vehicle wheels under intensive operating conditions. This paper constitutes a progress report in the research investigation being conducted by the Bureau of Public Roads with the cooperation of the Rubber Manufacturers' Association and the Society.

The test equipment, including the multiple-element contact accelerometer used to measure the impact forces, is described and the results are given in tabular and graphical forms.

Karrier Road-Rail Vehicle. Published in *The Automobile Engineer*, April, 1931, p. 127. **[J-1]**

The Karrier company claims that its Road-Rail Coach constitutes a successful solution of the many difficulties that must be overcome in designing such a vehicle. The author of the article points out that separate sets of conditions govern road and rail traffic and that each imposes a particular set of controlling factors.

The designing and testing of this vehicle have, it is stated, occupied two years. Simplicity and unobtrusive application are the essential features of the scheme developed. The Chaser-6 chassis was chosen for the foundation, since such considerations as rear buffers and the necessity for mid-entrance to the body, together with adequate rear clearance over the rails, rendered this particular chassis most suitable for the dual purpose.

The article covers in detail the frame, front and rear axles, wheels, transmission and numerous items of equipment.

PASSENGER-CAR

Will Rear-Engine Design Come Back? By P. M. Heldt. Published in *Automotive Industries*, April 25, 1931, p. 646. **[L-1]**

The past and present of the rear-engined car are reviewed in this article, the first of a series by P. M. Heldt, who tells why the engine was originally in the rear and how it was moved up ahead of the driver. The other articles that appear in succeeding issues of *Automotive Industries* are:

Do Today's Demands Obsolete Today's Designs? May 2, 1931, p. 682.

Rear-Mounted Engines Would Bring a Renaissance in Body Design, May 9, 1931, p. 718.

Advantages of Streamlining Lies in Power Economy at High Speeds, May 16, 1931, p. 762.

Dyke's Automobile and Gasoline-Engine Encyclopedia. By A. L. Dyke. Published by the Goodheart-Willcox Co., Inc., Chicago, 16th edition, 1931; 1233 pp., illustrated. Price, $7.50. **[L-2]**

This widely known reference book and instructor is now in its 21st year. The 16th edition has been extensively revised and enlarged and a supplementary index of more than 300 lines has been added to cover the new material. An idea of the completeness of the index is conveyed by the statement of the publishers, "over 15,300 lines of index."

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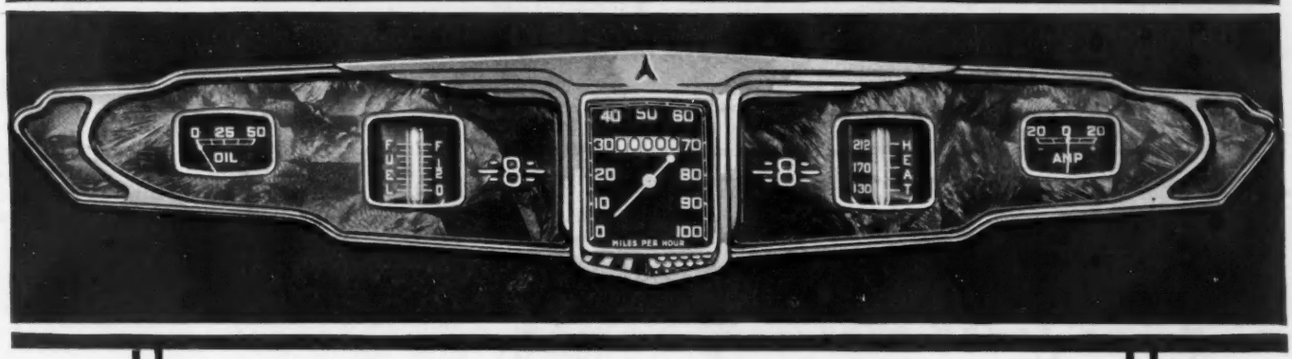

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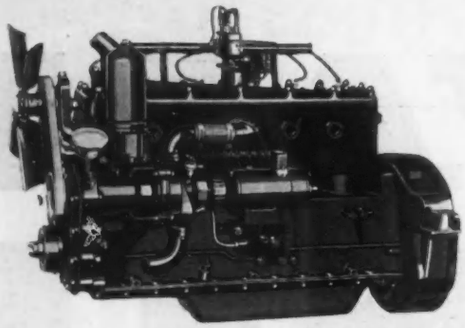

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SPECIFICATIONS

	Bore	Stroke	Displacement	H. P.
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E-601	3⅞	4½	318	80
E-602	4⅛	4½	360	90
E-603	4¼	4½	382	98

The Continental E-600 six cylinder series for trucks offers unusual efficiency and economy of operation in a closely graduated power range. These engines, having the same installation dimensions, are interchangeable in engine mountings. Special "dry-gas" manifolding and cylinder head design provide unusual horsepower per pound of weight and per cubic inch of displacement. Cooling system provides ample flow of water around all cylinder barrels and around valves. Exhaust valve ports are completely jacketed. Gear driven pressure feed oil system to all wearing parts assures long life.

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At all speeds, unusually high power output is coupled with economical operation.

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Personal Notes of the Members

(*Continued from p.* 171)

Wasp engine with which the craft is powered; C. M. Keys, president of North American Aviation, Inc.; Igor I. Sikorsky, president of the Sikorsky Aviation Corp.; Jerome C. Hunsaker, vice-president of the Goodyear-Zeppelin Corp.; Clarence D. Chamberlin; Edward V. Rickenbacker, vice-president, and Bernt Balchen, test pilot, of the Fokker Aircraft Corp. of America.

Ross and Fairfield Company Changes

Following the sudden death in July of Edward A. Ross, formerly president of the Fairfield Mfg. Co., of Lafayette, Ind., as well as of the Ross Gear & Tool Co., the directors of the two companies have announced the election of David E. Ross to the presidency of both companies and of A. J. McAllister as secretary-treasurer of the Fairfield Mfg. Co. Prior to 1927 David E. Ross was vice-president and general manager of the Ross Gear & Tool Co., which he had helped to develop from its beginning in 1906. He was the inventor of the Ross cam-and-lever steering-gear and is one of the largest stockholders in the company. Mr. McAllister has been identified with the Fairfield Mfg. Co. for a long time and was secretary and sales manager until being made secretary-treasurer last month.

Shidle Receives Editorial Awards

First and second prizes for editorial excellence during the year 1930 were awarded by the Associated Business Papers, Inc., on June 20 to Norman G. Shidle, directing editor of the Chilton Class Journal Co. publications. The first prize was for excellence of a series of articles written by Mr. Shidle on the merchandising of automotive parts, published in the issues of *Automotive Industries* for May 17, 24, and 31 and June 14, 1930. The second prize was for excellence of an editorial discussing the problem of merchandising machine-tools. Mr. Shidle is the only person who has won in the same year two of the three prizes offered.

The awards were established in 1926 and are offered annually to members of the editorial staffs of nearly 150 technical and business periodicals which are members of the American Business Papers, Inc. They are awarded respectively for the best article or series of articles and for the best editorials submitted during the year.

Mr. Shidle has been directing editor of the Chilton Class Journal publications for the last four years, having been editor of *Automotive Industries* for a number of years before that time. He has been a Member of the Society since 1921 and is Chairman of the Meetings Committee this year.

C. A. Winslow and J. Thysse with Standard Gas Engine Co.

Announcement has been received that Charles A. Winslow has become vice-president and general manager, and John Thysse has been appointed chief engineer, of the Standard Gas Engine Co., of Oakland, Calif. Their previous posts were, respectively, those of development engineer and assistant chief engineer of the Hercules Motor Corp., of Canton, Ohio.

Mr. Winslow, who has been a member of the Society since 1924, is widely known for his work in connection with the developing and manufacturing of H-W filters, Winslow carbureters, air-cleaners, breather-filters, and lubricating and crankcase-ventilating systems. Prior to this work for the Hercules concern, he was associated for about four years with the Sheet Steel Products Co., being stationed successively at Michigan City, Ind.; Vallejo, Calif.; and Chicago. He has been a member of the Detroit, Chicago and Northern California Sections.

Mr. Thysse received his engineering education in Holland and Germany and has been associated with leading Diesel marine-engine manufacturers in Europe. His American

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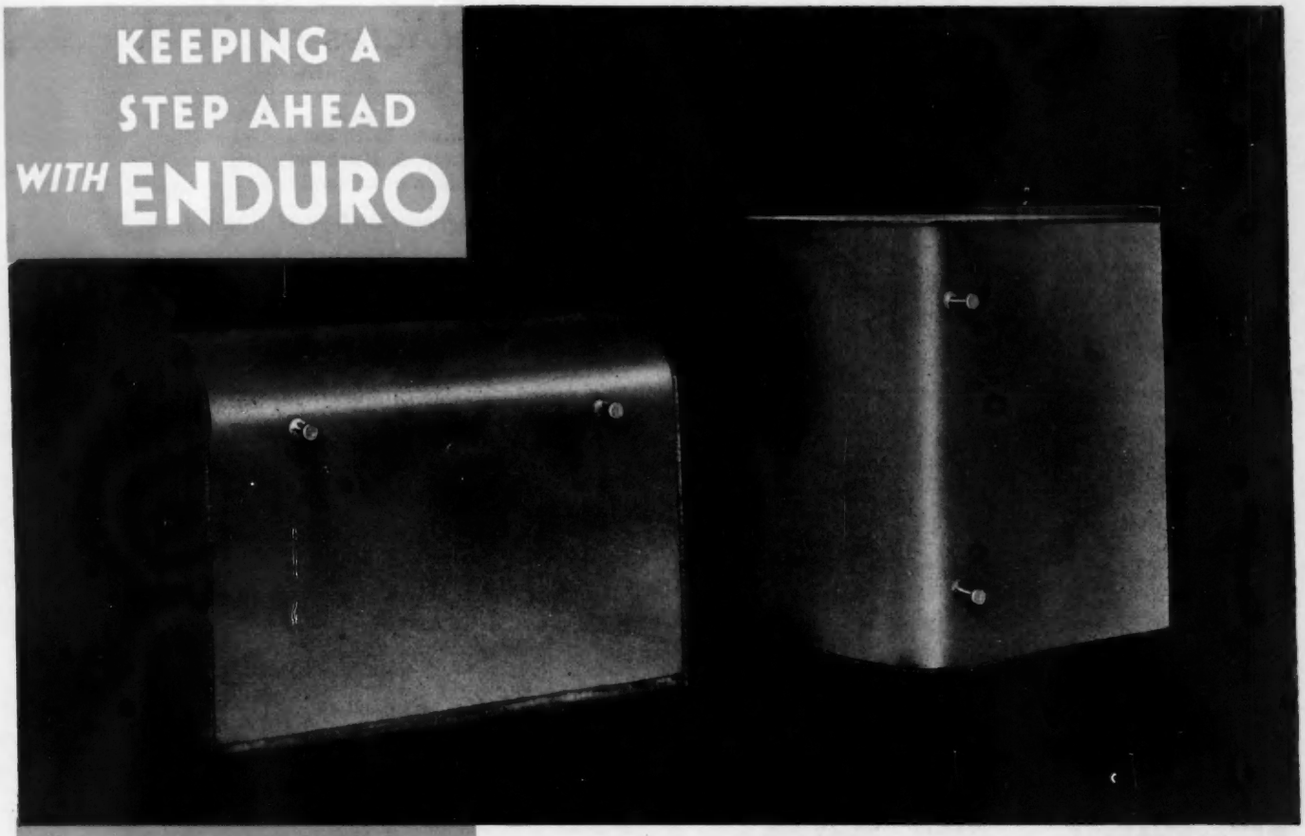

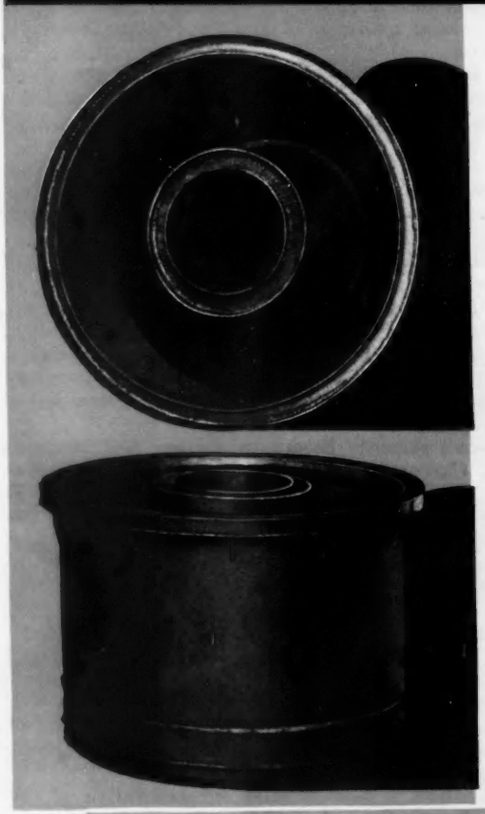

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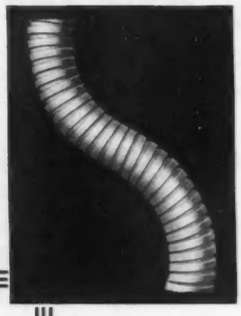

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REX-TUBE FLEXIBLE TUBING

Personal Notes of the Members

Continued

connections have been with the Diesel-engine division of the Worthington Pump & Machinery Co. and the Hill Diesel-Engine Co. He became a Member of the Society last year.

Degree Conferred upon Jehle

During the recent university commencement season, the advanced degree of Mechanical Engineer was conferred by the University of Illinois upon Ferdinand Jehle, research engineer of the White Motor Co., of Cleveland. Mr. Jehle, who became a member of the Society in 1911, has done notable research work in the industry, some of which has been reflected in several papers presented before the Society. Among these are the following:

Are Barometric Temperature and Humidity Readings of Value in Comparative Motor Tests?
Garland's Magnetic-Absorption Dynamometer
Laboratory Technique, Methods and Equipment
Use of Aluminum in Present and Future Motor-Cars
A Valve-Clearance Indicator
Aluminum Pistons
Idiosyncrasies of Valve Mechanisms and Their Causes.

Mr. Jehle is a member of the Research Committee, has been a member of the Publication Committee and has long been an active worker in the Cleveland Section.

H. J. Alter has assumed the duties of engineer and designer for Fleetwings, Inc., of Garden City, Long Island, N. Y. He previously was a student at New York University.

Stanton D. Barclay, having relinquished his post as instructor at Pratt Institute, of Brooklyn, N. Y., has accepted the post of general manager of the Feedwater Treatment Corp., of Boston.

Milton C. Baumann is now connected with the Great Lakes Aircraft Co., of Cleveland, Ohio. Before making this change he was chief engineer of the Inland Aircraft Co., of Kansas City, Kan.

William R. Blakely recently accepted the post of engineer with the Kreider Reisner Aircraft Co., of Hagerstown, Md. He was formerly connected with the Huntington Aircraft Corp., of Stratford, Conn., as assistant chief engineer.

Burton W. Brodt is now serving the Budd Wheel Co., of Detroit, as sales representative. He previously was connected with the Firestone Steel Products Co., of Akron, Ohio, as manufacurers' representative.

Robert E. Busey recently assumed duties as a designer for the Hupp Motor Car Co., of Detroit. He was formerly employed in a similar capacity with the Chrysler Motor Corp.

Federico Canali recently became a partner and manager of the firm of Carrozzeria Torinese, at Turin, Italy. Previous to this he was secretary on the technical staff in charge of the management of the rubber division of the Societa Italiana Pirelli, at Milan, Italy.

Charles N. Colstad has resigned his position as works manager and chief engineer of the Apco-Mossberg Corp., of Attleboro, Mass., after four years in that capacity, and will devote his entire time to consulting, design and research work, specializing in automotive accessories and equipment.

F. W. Cook, formerly with the Marvel Carburetor Co., has become associated with the Carter Carburetor Co. in an engineering capacity. He will be located in the Detroit office of the company.

Robert J. de Roza is now a sales representative of the Fageol Motor Truck Co., of San Francisco. His former connection was with the Federal Motor Truck Co. of California, also of San Francisco, as branch manager.

Robert N. Dobbins is now employed by American Airways, Inc., of Newark, N. J., as an inspector. He previously was chief instructor at the Institution of Aeronautics, New York City.

(*Concluded on next left-hand page*)

A Seamless Steel Tubing IDEAL *for* A THOUSAND USES

IN industry and transportation, wherever lightness, strength, safety and economy of construction are desirable, designers are specifying seamless steel tubing. Particularly, many designers are specifying "Pittsburgh" Seamless because of its accepted high quality and proved performance.

It is impossible to enumerate the number of purposes which Pittsburgh Seamless serves. In refineries, power plants, oil wells, refrigerating plants and numerous other industries where pressures, temperatures and corrosion are problems, it has served with distinction for years. In automobiles, trucks, locomotives, airplanes and ships, it has increased strength and eliminated excess weight. In stationary machinery it has increased safety and efficiency and effected many economies.

Undoubtedly Pittsburgh Seamless can serve you as efficiently and economically as it is serving countless others. It is furnished in special shapes and in most of the S. A. E. series of steel alloys. May we discuss your requirements?

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Pittsburgh P Seamless

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SPRING MAKERS FOR THREE GENERATIONS

WHEN you require cooperation in the design or other factors associated with the use of Springs, won't you take advantage of our special engineering resources?

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Practical Springmakers
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BRISTOL CONN.

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SPRINGS STAMPINGS ASSEMBLIES SPRING WASHERS SCREW MACHINE PARTS COLD ROLLED SPRING STEEL

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The Versatile Product

AMERICAN FELT COMPANY, largest Felt manufacturers in the world, would gladly cooperate with your engineers in solving the most difficult problems. The diversified uses of Felt are really amazing.

Our complete and modern Felt Cutting Plant at Detroit, as well as our five Felt Mills, has provided the Automotive Industry with an entirely dependable source of supply. We are fully equipped to supply Felt in bulk or cut to the most exacting specifications.

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General Offices
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Personal Notes of the Members
Concluded

Laurence J. Grunder has accepted a position with the Southern division of the Richfield Oil Co., of California, as an automotive engineer and is located at Los Angeles. Prior to this change he served the Hughes Development Co., Ltd., of Hollywood, as automotive research engineer.

Randolph F. Hall, formerly of the Thomas-Morse Aircraft Corp. and until recently chief engineer of the Cunningham-Hall Aircraft Corp., of Rochester, N. Y., has resigned from the latter company.

Kenneth R. Herman, who was chief engineer of the Divco Detroit Corp., of Detroit, recently accepted a post with Vickers, Inc., as development and sales engineer, with headquarters in Detroit.

S. K. Hoffman has accepted a position as engineer with the Lycoming Mfg. Co., of Williamsport, Pa. Up to the time of accepting his present post he was research engineer in the General Motors Corp. Research Laboratory in Detroit.

Charles I. Hummer, formerly engineer with the U. S. Wheel Track-Layer Corp., of Rahway, N. J., is now employed by the Magar Car Corp., of Passaic, N. J.

Leland A. Hurd is now Air Corps representative in charge of inspection for the United States Army Air Corps, and is located at Buffalo. He was formerly airplane pilot in the Air Corps, located at Wright Field, Dayton, Ohio.

Having relinquished his duties as experimental engineer in the special study department of the General Motors Corp., in Detroit, **Andrew L. Kimball** is now engaged in similar duties with the Olds Motor Works, of Lansing, Mich.

James F. Knudson, Jr., has assumed duties as president of the Knudson-Frohm Motor Sales, at Buffalo. He was previously chief checker for the Curtiss Aeroplane & Motor Co., at Kenmore, N. Y.

Hans W. Lindemann, formerly passenger-car chassis designing engineer for the Nationale Automobil-Gesellschaft, of Berlin, Germany, recently accepted the post of designing engineer with the Büessing-Nag works, at Leipzig, Germany.

Walter M. Lipps has been appointed sales representative in the Indianapolis district for the Russell Mfg. Co., of Detroit. His prior connection was with the American Cable Co., of Detroit, as assistant chief engineer in the automotive division.

Donald J. Lowman has accepted the post of experimental engineer in the engine division of the American Plane & Engine Co., of Farmingdale, N. Y. He previously served as an engineer in the aeronautic division of the Lycoming Mfg. Co., of Williamsport, Pa.

Leonard V. Newton, automotive engineer of the Byllesby Engineering & Management Corp., of Chicago, and a member of the Transportation and Maintenance Committee of the Society, was appointed a member of the Aeronautic Commission of the City of Chicago by Mayor Cermak at a meeting of the City Council in July.

Harry E. Miller recently assumed proprietorship of the C. & M. Battery Service, of Orange, N. J.

John Gates Monjar, formerly sales manager of the Detroit Gear & Machine Co., is now associated with the Warner Gear Corp., of Muncie, Ind., in a sales capacity.

John J. O'Brien is now associated with the Buhl Aircraft Co., of Detroit. He was formerly vice-president and general manager of the Motor & Plane Accessories, Inc., also of Detroit.

C. C. Trump is now connected with the James Spear Stove & Heating Co., of Philadelphia. He used to be president and mechanical engineer of the Trump Corp., of Syracuse, N. Y.

William N. Whitacre has recently been made district sales manager for the Tyson Roller Bearing Corp., of Cleveland.

Alfred Tucking, a former designer for the Packard Motor Car Co., of Detroit, is now employed by the Chrysler Corp., of Highland Park, Mich., as a mathematician.